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Queen's University
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Transportation Development Centre

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VIDEO-RECORDED DRIVER BEHAVIOUR AT RAILWAY CROSSINGS: APPROACH SPEEDS AND CRITICAL INCIDENTS

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prepared for
Transportation Development Centre

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17. Abstract

Driver approach behaviour at seven railway level crossings in Ontario was recorded on video tape during 301 hours. The crossings varied according to protection (crossbucks only, flashing lights and bells, and gates) and urban versus rural location. Hourly traffic flow (in both directions combined) ranged from a maximum of approximately 900 to a minimum of about 2 vehicles. The records were analyzed qualitatively for the occurrence of critical incidents, defined as events that bring an accident appreciably closer to its potential realization. Most of the critical incidents took the form of road users either inadvertently or deliberately entering the crossing after signal onset. Critical incidents were common events; they were seen in about two-thirds of all periods in which the warning signals were activated. Unduly long warning times, long occupancy times of the crossings by some trains and false alarms (i.e. between signal onset and cancellation no train appears at the crossing) were interpreted to stimulate the tendency of road users to deliberately violate the signals. Inadvertent violation of the signals was explained as a result of the physical impossibility to come to a safe and comfortable stop in front of a crossing which inevitably applies under certain conditions (of onset time of signal, driver location and approach speed). Driver approach speeds of about 3200 lead vehicles were analyzed quantitatively from the video records and showed high coefficients of speed variation between drivers as well as within drivers as they moved closer to the crossings. During a rail strike drivers approached crossings at a higher speed than they did under normal conditions.

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17. Résumé

Le comportement des conducteurs de véhicules à l'approche de sept passages à niveau en Ontario a été enregistré sur bandes vidéo pour une durée de 301 heures. Ces enregistrements concernaient des passages à niveau comportant des protections variées (croix de St-André seulement, feux clignotants avec sonnerie, et barrière) et situés tant en milieu urbain qu'en milieu rural. Le débit horaire de la circulation dans les deux sens variait d'un maximum de quelque 900 à un minimum de 2 véhicules. Les résultats ont été dépouillés pour y repérer tous les cas d'incidents à caractère critique définis comme étant un événement où la probabilité d'un accident a été augmentée sensiblement. La plupart de ces incidents critiques avaient pris la forme d'un franchissement involontaire ou délibéré du passage à niveau à un début de phase de feux clignotants. Ce type de comportement a été fréquent, ayant été observé pour près des deux tiers de périodes de rouge. L'infraction volontaire s'explique par un signal avancé de passage d'un train trop précoce, des temps de passage de trains très longs ou un signal erroné (aucun train entre le début et la fin de phase), tous ces facteurs ayant été interprétés comme étant des encouragements aux conducteurs à commettre volontairement une infraction. Quant aux infractions involontaires, elles s'expliquent par l'impossibilité d'effectuer un arrêt normal et sécuritaire au passage à niveau pour des raisons reliées à la position et vitesse du véhicule au moment de déclenchement du signal. La vitesse de quelque 3200 véhicules de tête à l'approche des passages à niveau a été calculée à partir des enregistrements. De fortes variations ont été constatées sur ce plan, tant d'un véhicule à l'autre que, pour un même véhicule, à divers instants de son approche. À l'occasion d'une grève des chemins de fer, la vitesse d'approche des passages à niveaux a été supérieure à celle pratiquée normalement.

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EXECUTIVE SUMMARY

The objective of this study was to add additional information to the existing data base describing critical incidents that occur at level railway crossings under normal operating conditions. The critical incident technique involves the collection and analysis of data on failures, errors, "narrow escapes," near-accidents, etc., and is thus complementary to the analysis of reported accidents. Critical incidents may be loosely defined as events that bring an accident significantly closer to its potential realization, although no reportable accident actually occurs. As a group, these events may be viewed as necessary, but insufficient conditions for the occurrence of accidents.

Critical incidents occur much more frequently than do accidents. Earlier studies by Wilde *et al.*, observed critical incidents in about 50% of all activation periods of crossing signals at six Eastern Ontario sites. As a consequence, critical incidents represent a much more practical data base for the study of driver behaviour at crossings than do accidents themselves.

However, earlier studies could not provide any permanent record of motor vehicle movements and driver behaviour. Modern videotape equipment makes the recording of observations quite feasible. Videotaped records offer several major advantages: unlimited opportunity for re-analysis, the ability to exchange data with other researchers and safety practitioners, and availability of the material for visual demonstration and educational purposes.

In addition to serving the objective of recording and analyzing critical incidents (both in the absence and presence of train approach), the video records were used to carry out a quantitative analysis of motor-vehicle approach speeds and speed changes (when the lights were not flashing and no train whistle could be heard to announce its approach).

In the course of the study, a strike by railway workers halted all train movements. This offered an opportunity to compare driver behaviour during a period of time in which the signals and barriers would not be activated, with behaviour during periods of normal train operations.

Video recordings with voice-over narrative were made by a two-person observation team at seven railroad crossings in Ontario. Table A summarizes the characteristics of these crossings.

All observations were made during full daylight. Observations took place during the summer of 1987 in dry weather. The team was positioned unobtrusively, so as not to influence driver behaviour.

The camera recorded all approaching (one side of the crossing) vehicles within about 100 metres of the crossing, but concentrated on the railway crossing itself immediately after the crossing signals or train whistle were activated. Thus, the motor vehicles filmed when the lights were not flashing (or no train was approaching) were different from the traffic videotaped during actual train approach.

Table A: Characteristics of the Sampled Crossings

Location		Speed Limit (km/h)	No. of Tracks	No. of Lanes	Protection Type	Hourly Flow (both ways)	Direction Observed	Far Zone Length (in m.)	Near Zone Length (in m.)
Kingston, Counter Street	urban	50	2	2	gates	699	NE	41.1	14.2
Oshawa, Wilson Street	urban	50	2	2	gates	461	N	28.3	41.0
Oshawa, Adelaide Street	urban	50	3	4	FL&B	903	N	n.a.	n.a.
Belleville, Dundas Street	suburban	60	1	4	FL&B	540	W	27.0	31.0
Roblin, Highway 41	rural	70	2	2	FL&B	241	S	75.0	59.0
Deseronto, Deseronto Road	rural	80	2	2	crossbks	3	N	142.0	57.0
Marysville	rural	80	2	1	crossbks	2	N	74.6	13.0

NOTE: n.a. = not applicable

To permit quantitative speed measurement, existing landmarks were used to demarcate two zones, one farther away from each crossing (the "far zone"), and one immediately adjacent to each crossing (the "near zone"). Speeds were measured for the lead vehicle in a platoon approaching the crossing. Descriptive statistics were used to characterize speed behaviour in each observation zone. These statistics were calculated for the aggregate lead vehicles, as well as for three separate vehicle categories: (a) cars, (b) small trucks, including vans and pick-up trucks, and (c) large vehicles, including tractor-trailers, buses and motor homes.

In addition to vehicular flow data, train and signal data were recorded. At each crossing, the number of train approaches during the observation period was noted, along with the durations of "warning time" as well as the "total signal durations." Descriptive statistics were calculated for both temporal aspects of signal activation. The observation crew also identified the occurrence and durations of false alarms (i.e., no train actually occupied the crossing in the time period between the onset and the cancellation of the crossing signals).

A total of 65 critical incidents were recorded during 287 observation hours. Critical incidents occurred in approximately two-thirds of the train approaches.

The speed data showed considerable variation in approach speed at any individual crossing, in both near and far zones. For instance, the difference between the fastest and the slowest vehicle in this zone amounted to 63 km/h at the Kingston crossing, to 79 km/h at the Wilson Street crossing in Oshawa, to 88 km/h at the Belleville crossing, and at the Roblin crossing the fastest vehicle moved 56 km/h faster than the slowest.

A comparison of average speed in the far zone and the posted speed limit shows that at the Kingston crossing, drivers moved on average about 13.5 km/h faster than the limit; in Oshawa they exceeded the limit on average by 17 km/h; for the Belleville crossing the overspeed was 12.5 km/h; while at the Roblin crossing average speed was about 6 km/h lower than the posted speed limit.

Variations between speeds in the near zone were also found to be very marked at each of the crossings. In this zone the average speed at the Kingston crossing was well below the posted speed, in Oshawa (Wilson Street) it exceeded the speed limit by about 13 km/h, and at the Belleville crossing by about 5 km/h.

Analysis of observations during the railway strike showed that drivers approached crossings at higher speeds than during normal operations, with the greatest observed increase being for large vehicles (trucks, buses, motor homes).

There was also considerable variation in observed warning times, both within and between crossings in the study sample.

Average warning times were longest at the Belleville crossing (73 seconds), with the shortest observed warning time at that crossing being 45 seconds. The greatest variability from one signalling period to another at the same crossing was observed at the Wilson Street crossing in Oshawa (coefficient of variation = 1.11). The very short minimum warning time observed at the Kingston crossing (13 seconds) occurred immediately following a false alarm. The average duration of warning times that immediately followed the false positive signal activations at Kingston was 17.9 seconds; the longest lasted 25 seconds.

False alarms were observed only at the Kingston station crossing, but there they occurred quite often, in 21 of 41 alarm periods observed. In fact, these false alarms always occurred when an eastbound passenger train approached the station (about 150 metres west of the crossing). The shortest false alarm lasted 2 minutes and 11 seconds, the longest 2 minutes and 46 seconds.

False alarms, like unduly long warning times, undermine the credibility of railway signals. False alarms encourage drivers to decide for themselves whether it is safe to cross, and in doing so they may make a catastrophic error.

Total signal durations were measured from the onset to the cancellation of the flashing signal. Major variations between crossings were found. The significance of total signal duration for driver behaviour stems from the fact that the longer the expected signal duration, the greater the temptation for drivers to negotiate the crossing before the train occupies it. Long total signal durations foster the tendency to try to "beat the train to the crossing" and to wilfully disobey the signal in the first seconds after its onset.

Many of the problems (accidents, critical incidents, high speed variation) that occur at railway crossings arise from the following main sources:

- Some drivers are not aware they are approaching a crossing or are not aware of a train. This lack of awareness typically accounts for one-quarter to one-third of train/vehicle collisions.

- Some drivers who are aware meet with the "unobeyable signal problem": the signals begin to flash when the driver is unable to bring the vehicle to a safe and comfortable stop. This is a common occurrence.

- When approaching a crossing while the signals are not flashing, the driver may reduce the likelihood of the above event in two contrasting ways: the driver may either slow down (thus reducing the time required to stop in case the signals come on) or speed up (to reduce the exposure time). Both actions are sensible, but lead to speed variance, which in turn increases the incidence of vehicular collisions. About two-thirds of all collisions at crossings involve no train, and most occur between vehicles travelling in the same direction.

- Deliberate disregard for the signals is encouraged by long warning periods, long total signal durations and false alarms. An activated signal does not always imply imminent train approach. Conversely, an unactivated signal is not generally interpreted by drivers to mean that no train is approaching.

As in other situations with unclear, ambiguous stimuli, the opportunity is created for the occurrence of two types of risky decisions:

(a) to heed the warning when in fact no train is forthcoming, and
(b) to disobey the signals although in fact train approach is imminent.

As the first decision is taken by some but not by all drivers, variance in approach speeds is exacerbated and increases the likelihood of rear-end collisions between highway vehicles. The second entails the same source of risk as the first, but in addition entails the possibility of colliding with a train.

The second decision becomes more attractive to the driver when:

(1) the ratio of false signals relative to valid signals is high;
(2) warning times are long;
(3) trains occupy crossings for extended periods of time.

For the purpose of safety promotion at railway crossings, false alarms should be eliminated. The perceived value of the decision to disobey the signal will be smaller to the extent that warning times are kept short as are the total durations of trains occupying the crossing (i.e. when trains are short and move fast).

In summary, efforts toward risk control -- short of grade separation -- should be aimed at increasing crossing conspicuity, at reducing the occurrence of unobeyable signals, at improving the smoothness of crossing surfaces, at the elimination of false alarms and excessively long warning periods, and at the reduction of the total duration of signal activation.

SOMMAIRE

La recherche avait pour but d'enrichir la base de données concernant les incidents à caractère critique qui ont lieu à un passage à niveau dans des circonstances normales. Il s'agissait de recueillir et d'analyser des données sur les cas d'omissions, d'erreurs, d'incidents graves, d'accidents évités de peu, etc., en complément des analyses d'accidents formellement constatés. Un incident à caractère critique peut être défini en gros comme une situation où un accident a été évité de justesse, mais qui ne donne pas lieu à un constat. Ces incidents ont tous pour caractéristique commune d'être essentiels à la réalisation d'un accident sans pour autant suffire à eux seuls à causer l'accident.

Les incidents critiques sont plus nombreux que les vrais accidents. Des études antérieures effectuées à six passages à niveau, en Ontario, avaient permis d'observer des incidents de ce type à l'occasion d'environ 50 p. 100 des cycles de rouge. C'est pourquoi ces incidents constituent une base de recherche pratique plus utile à l'étude du comportement des conducteurs à l'approche d'un passage à niveau qu'aux accidents proprement dits.

Cependant, ces études se résumaient à des observations et ne livraient aucun enregistrement permanent du comportement des véhicules impliqués ou des conducteurs. Grâce aux techniques modernes d'enregistrement magnétoscopique, on dispose aujourd'hui d'enregistrements permettant une analyse répétée, l'échange d'information avec d'autres chercheurs ou spécialistes en sécurité routière et la création d'une documentation visuelle utile à des fins d'information et d'éducation.

En plus de permettre l'enregistrement et l'analyse des cas d'incidents critiques avec ou sans passage de train, la recherche a permis de procéder à une analyse quantitative des résultats concernant les vitesses à l'approche du passage à niveau et les variations de ces vitesses, alors qu'il n'y avait ni feux qui clignotaient, ni avertisseur annonçant l'arrivée d'un train.

Une grève déclenchée par les cheminots, interrompant toute circulation ferroviaire, a fourni aux chercheurs l'occasion de comparer le comportement des conducteurs dans deux cas précis: 1) lorsqu'aucune signalisation ne risque d'être déclenchée; 2) en période de trafic ferroviaire normal.

Une équipe de deux observateurs a réalisé des enregistrements sur bandes vidéo accompagnés de commentaires parlés. Le tableau 1 ci-dessous donne les caractéristiques de sept passages à niveau observés en Ontario:

Caractéristiques des passages à niveau

	Emplacement	Limite de vitesse affichée (km/h)	Nombre de voies ferrées	Nombre de voies routières	Type de protection	Débit horaire (deux sens)	Direction observée	Longueur zone éloignée (m)	Longueur zone proche (m)
Kingston, Counter St.	urbain	50	2	2	barrières	699	NB	41,1	14,2
Oshawa, Wilson St.	urbain	50	2	2	barrières	461	N	28,3	41,0
Oshawa, Adelaide St.	urbain	50	3	4	FC & S	903	N	s.a.	s.a.
Belleville, Dundas St.	suburbain	60	1	4	FC & S	540	O	27,0	31,0
Roblin, Highway 41	rural	70	2	2	FC & S	241	S	75,0	59,0
Descronto, Descronto St.	rural	80	2	2	Croix St-André	3	N	142,0	57,0
Marysville	rural	80	2	1	Croix St-André	2	N	74,6	13,0

NOTE: s.a. = sans objet
FC & S = feux clignotants et sonnerie

A noter que les observations se faisaient en plein jour, en plein été (1987) et par temps sec. Quant à l'équipe d'observation, elle se tenait discrètement hors de vue des conducteurs afin de ne pas influer sur leur comportement.

Les véhicules venant d'une direction donnée étaient filmés dès qu'ils entraient dans la zone éloignée, commençant à quelque 100 m du passage à niveau. Toutefois, aussitôt que la signalisation était déclenchée ou que le train signalait son approche par un avertissement sonore, la caméra était braquée sur le passage proprement dit. Donc, les véhicules filmés quand la voie était libre sont différents de ceux qui l'ont été à partir du moment où un train était signalé.

Afin de faciliter la détermination des vitesses, deux zones ont été définies, délimitées par des repères visibles: une zone éloignée du passage à niveau et une autre contiguë à celui-ci. Pour chaque peloton de véhicules s'approchant du passage à niveau, la vitesse du véhicule de tête a été calculée à partir des enregistrements. Quant aux vitesses pratiquées dans les deux zones d'observation, elles ont été caractérisées par des statistiques descriptives établies pour l'ensemble des véhicules de tête et pour trois catégories distinctes de véhicules: a) automobiles, b) fourgonnettes et utilitaires légers ainsi que c) poids lourds: ensembles tracteurs-remorques, autocars et caravanes.

Les chercheurs ont aussi enregistré les données concernant les trains et la signalisation de protection, soit: nombre de trains par période d'observation, durée du "signal avancé de passage" et "durée totale de la période rouge". Des statistiques descriptives ont servi à caractériser ces deux aspects de la signalisation. Le nombre et la durée des signaux erronés (aucun passage de train entre le début et la fin de la phase de rouge) ont également été notés.

Un total de 65 incidents critiques ont été enregistrés en 287 heures d'observation, soit près du tiers du nombre de passages de train.

A tous les postes d'observation, des écarts importants ont été constatés dans les vitesses d'approche dans les deux zones d'observation. Ainsi, l'écart entre le plus rapide et le moins rapide des véhicules dans la zone éloignée a été de: 63 km/h à Kingston, 79 km/h à Oshawa (rue Wilson), 88 km/h à Belleville et 56 km/h à Roblin.

La comparaison entre la moyenne des vitesses pratiquées dans la zone éloignée et la vitesse limite affichée montre un dépassement de quelque 13,5 km/h à Kingston, de 17 km/h à Oshawa et de 12,5 km/h à Belleville; par contre, à Roblin, la vitesse moyenne a été de quelque 6 km/h inférieure.

A l'égard de la zone proche, des écarts marqués de vitesse ont été également observés à tous les postes d'observation. A Kingston, la vitesse moyenne pratiquée a été très inférieure à la vitesse limite affichée, mais supérieure de 13 km/h à Oshawa (rue Wilson) et de 5 km/h environ à Belleville.

Les observations faites durant la grève des cheminots en 1987 ont mis en évidence des vitesses d'approche plus élevées qu'en temps normal, les plus grands écarts se trouvant dans la catégorie des poids lourds.

Une autre constatation faite a été la variation considérable dans la durée observée du signal avancé de passage d'un train, aussi bien d'un passage à niveau à un autre, qu'à un même passage.

La durée moyenne de ce signal a eté la plus longue (73 s) à Belleville où le signal le plus court a été de 45 s. La variation la plus marquée entre deux signaux consécutifs a été observée à Oshawa (rue Wilson): coefficient de variation = 1,11. La plus courte durée observée à Kingston (13 secondes seulement) s'est produite juste après un signal erroné. La durée moyenne des signaux avancés se produisant juste après un signal erroné à Kingston a été de 17,9 s, la plus longue ayant été de 25 s.

De tels signaux erronés n'ont été observés qu'à Kingston, mais leur fréquence a été élevée: 21 sur un total de 41 cycles de rouge; ils se produisaient toujours lorsqu'un train de voyageurs circulant en direction est se trouvait à quelque 150 m à l'ouest du passage à niveau. La durée des signaux erronés a varié entre 2 min 11 s et 2 min 46 s.

Les signaux erronés, tout autant que les signaux avancés de passage trop précoces, ont l'effet d'augmenter le danger aux conducteurs; ils les incitent à s'aventurer sur la voie, au risque de commettre une erreur fatale.

A chacun des passages observés, la durée totale des cycles de rouge a été mesurée et d'importantes variations constatées d'un passage à l'autre. Cette durée revêt une importance considérable car plus la durée anticipée est grande, plus les conducteurs sont tentés de franchir le passage avant que le train ne s'y engage. Une durée excessive du cycle de rouge risque de pousser les conducteurs à vouloir devancer le train et à commettre délibérément une infraction en début de cycle.

Une bonne partie des événements se produisant aux passages à niveau (accidents, incidents critiques, changements marqués de vitesse) peuvent être attribués à l'une ou l'autre des principales causes suivantes:

- Conducteur qui ignore l'existence d'un passage à niveau ou de l'approche d'un train, facteur comptant pour le quart ou le tiers des cas de collision entre un train et un véhicule routier.

- Conducteur qui n'a pas obéi au signal n'ayant pu arrêter son véhicule à temps. Ce cas est fréquent.

- Afin d'éviter l'éventualité ci-dessus, le conducteur qui s'approche d'un passage quand le signal n'est pas (c'est à dire, n'est pas encore) activé, a deux moyens disponibles à ce but: il est amené soit à ralentir (pour avoir le temps de freiner), soit à accélérer (pour réduire le temps de franchissement). Ces deux initiatives se défendent, mais elles entraînent un changement d'allure qui, à son tour, augmente le risque de collision des véhicules entre eux. Près des deux tiers des collisions survenant aux passages à niveau n'impliquent pas de train et se produisent entre des véhicules allant dans la même direction.

- Infraction délibérée pouvant s'expliquer par un signal avancé trop précoce, une durée de cycle de rouge excessive ou un signal erroné. Le déclenchement d'un signal n'est pas forcément perçu comme l'annonce du passage imminent d'un train. Inversement, l'absence de signal n'est pas toujours interprétée comme signifiant que la voie est absolument libre.

Comme dans toutes les situations ambiguës, deux décisions risquées sont possibles:

(a) obéissance du signal alors que la voie est libre, et
(b) infraction délibérée malgré l'approche imminente du train.

La première, qui sera prise par seulement quelques-uns des conducteurs, a pour conséquence de creuser davantage les variations de vitesse et d'augmenter les risques de collision des véhicules entre eux. La seconde implique, en outre, le risque de collision avec le train. Mais elle pourra sembler intéressante à certains conducteurs :

1) si le rapport des signaux erronés aux signaux justifiés est élevé;

2) si les signaux avancés sont trop précoces;

3) si les trains mettent beaucoup de temps pour franchir le passage à niveau.

Pour accroître la sécurité des passages à niveau, il faudrait éliminer les signaux erronés et atténuer aux yeux des conducteurs impatients la valeur du temps qu'ils espèrent gagner en commettant une infraction, par une durée plus courte des signaux avancés de passage et par des trains moins longs et plus rapides occupant moins longtemps le passage à niveau.

En résumé, les efforts visant à réduire les risques d'accident aux passages à niveau doivent aller, à défaut de la construction de voies dénivelées, dans le sens d'une visibilité plus grande, d'une réduction des cas d'infraction involontaire, d'une amélioration de la surface de franchissement, de l'élimination des signaux erronés ainsi que d'une réduction de la durée des signaux avancés et du cycle de rouge.

TABLE OF CONTENTS

1. INTRODUCTION 1

2. METHOD 3
   2.1 General 3
   2.2 Selection of Crossings 3
   2.3 Apparatus 5
   2.4 Quantitative Speed Measurement 5
   2.5 Collection of Train and Signal Data 6

3. FINDINGS AND INTERPRETATIONS 7
   3.1 Critical Incidents 7
   3.2 Data on Vehicular Speeds in the "Far Zone" and the "Near Zone" 11
   3.3 Comparisons Between Vehicular Speeds in the Far and Near Zones 13
   3.4 Data on Warning Times 17
   3.5 Data on False Alarms and Total Signal Durations 17
   3.6 Vehicle Approach Speeds During a Railway Strike as Compared to Normal Conditions 18

4. DISCUSSION 21

5. SUGGESTIONS FOR FUTURE RESEARCH 26
   5.1 The Potential Benefits of a Bi-directional Signal Indicating that a Train is Approaching Either from the Left, the Right, or Both 26
   5.2 The Potential Benefits of a "Fail-safe" Signal 26
   5.3 The Resting Position of the Nonactivated Barrier as an Aid to Crossing Conspicuity 27
   5.4 The Safety Implications of Crossing Surface Roughness 27
   5.5 The Sequential and Standardized Warning Signal System (SSWS) 28
      5.5.1 Background 28
      5.5.2 Summary description of the SSWS design 30
      5.5.3 Implications of the SSWS system 32
      5.5.4 SSWS and crossing conspicuity 33
   5.6 The Relationship Between Lateral Sight Distance and Crossing Safety 34

REFERENCES 36

LIST OF TABLES

1. Characteristics of the Sampled Crossings 4
2. Critical Incidents 8
3. Speeds in the Far Zone 10
4. Speeds in the Fear Zone 10
5. Speed Change from the Far Zone to the Near Zone 12
6. Warning Time Durations 12
7. False Alarms, Critical Incidents and Total Signal Durations 17
8. Speeds and Speed Reduction from the Far to the Near Zone During the 1987 Railway Strike 19

LIST OF FIGURES

1. Diagram Illustrating the Method of Speed Measurements 5
2. Speed Change Distribution at Kingston 14
3. Speed Change Distribution at Wilson Street in Oshawa 14
4. Speed Change Distribution in Belleville 15
5. Speed Change Distribution in Roblin 15
6. Speed Change Distribution in Deseronto 16
7. Speed Change Distribution in Marysville 16
8. Schematic Diagram of the Sequential and Standardized Warning Signal System . 30

1. INTRODUCTION

The objective of this study was to bring additional information to the existing data base describing critical incidents that occur at level railway crossings under normal operating conditions. The critical incident technique involves the collection and analysis of data on failures, errors, "narrow escapes", near-accidents, etc. (Chapanis, 1970) and is thus complementary to the analysis of reported accidents. Critical incidents may be loosely defined as events that bring an accident significantly closer to its potential realization (Wilde *et al.*, 1975, 1976), while no reportable accident actually occurs. Such events are judged to significantly increase the likelihood of an accident occurring. As a group, these events may be viewed as necessary, but not sufficient for the occurrence of accidents. On the one hand, for a train-car collision to occur at a signalized crossing (supposing that the signals are properly operating), it is necessary that a car occupies the crossing after signal onset. On the other hand, the presence of a car on the crossing after signal onset is not a sufficient condition for an accident to take place.

A particular application of the critical incident technique in the area of road traffic is the traffic conflict technique, which is based on the systematic observation of road-user behaviour under normal (i.e., non-accident) circumstances. Generally speaking, a conflict is said to occur if a road user has to take evasive action (braking or swerving) to avoid a collision with another road user who has made an unusual or unexpected manoeuvre. The observed frequency of occurrence of conflicts and their type may be used to predict the number and types of reportable accidents occurring in the same or similar traffic location. Depending upon the type of conflict and accident in question and upon the stringency of the definition of a conflict, the ratio between the frequency of conflicts and accidents has been calculated to vary between approximately 1,500 to one and 700,000 to one (Glauz and Migletz, 1980, Figure G-7, p.83; Glauz and Bauer, 1985, p.364; Gårder, 1985, p.350; Hauer and Gårder, 1986).

Identification and analysis of critical incidents at railway crossings may assist in the understanding of the mechanisms involved in the causation of accidents at these sites and thus ultimately be helpful to the rational design of effective railway crossing protection. As these incidents are much more frequent than accidents, they offer, in principle, a much more practical data base for the study of driver behaviour at these sites. An earlier study, which involved systematic observation of driver behaviour at railway crossings under normal conditions, showed that critical incidents are indeed by no means rare events. In fact, they were observed with an average frequency of about one per hour and occurred in about one-half of all activation periods of crossing signals in a sample of six railway crossings in eastern Ontario (Wilde *et al.*, 1975,1976).

Among the various types of studies related to railway crossing "unsafety," it would seem -- apart from the critical incident technique -- that those taking the form of systematically observing driver approach behaviour under normal circumstances (i.e., not in conjunction with the occurrence of particular accidents) have been quite productive in identifying behaviourial factors that contribute to the accident potential of these sites (Åberg, 1984, 1987; Heilman, 1986; Hauer and Wilde, 1987; Sanders, 1975, 1976; Shinar and Raz, 1982; Wigglesworth, 1978; Wilde *et al.*, 1975, 1976).

However, while these studies monitored important variables such as driver approach speed, speed changes, speed-change reversals and head movements (indicating visual search for

trains), no permanent (cinematographic) record has, so far, been made of motor vehicle movements and driver behaviour. Recent advances in video technology have established the feasibility of such recording in observational studies. Video-taped records offer several major advantages: unlimited opportunity for re-analysis, exchange of more true-to-life (and less abstracted) data with other researchers and safety practitioners, and availability of the material for visual demonstration and educational purposes.

Thus, one objective of the present study was to explore the usefulness of a video recorder in collecting and analyzing cinematographic documentation material of critical incidents at level railway crossings, both in the absence and in the presence of train approach. Moreover, by means of a quantitative analysis of motor-vehicle approach speeds and speed changes calculated from the video recordings, an opportunity was offered to compare findings with those of earlier studies.

In the course of the study, railway workers went on strike (unanticipated by the present researchers) and train movements came to a complete halt. This offered a serendipitous opportunity for comparing driver approach behaviour at railroad crossings at a point in time at which the signals and the barriers could not possibly be activated with their behaviour at other, i.e., normal times.

2. METHOD

2.1 General

The observation crew, consisting of two persons, made video and narrative (audio) tape recordings (on the same tape) of driver approach behaviour at seven railroad crossings in Ontario. Some of these were protected with gates, some with flashing lights and bells (FL&B) and some with crossbucks only. Some were located on rural roads and some in built-up areas. All observations took place in full daylight and were made in an unobtrusive manner so as not to influence driver behaviour. (Originally it had been planned to collect video records of traffic at night as well, but the quality of several hours of pilot-test material was deemed unsatisfactory for analysis.) The camera recorded all approaching (one side of the crossing) vehicles within 100 metres or so from the crossing, but was zoomed in on the railway crossing itself as soon as the observation crew detected that crossing signals or train whistle were activated. Thus, the motor vehicles filmed when the lights were not flashing (or no train was approaching) were different from the traffic video-taped during train approach. Observations took place during the summer of 1987 in dry weather.

2.2 Selection of Crossings

Crossings were carefully selected on the basis of:

(1) diversity in the type of protection in place;

(2) comparable surface smoothness;

(3) diverse expected vehicular approach volumes and train volumes;

(4) the absence of sideroads or stores in the close proximity of the crossing (in order to exclude turbulence in speed due to that factor);

(5) urban and rural locations within 250 km from Kingston, Ontario;

(6) the physical possibility of setting up the video camera in a place appropriate for filming critical incidents on the crossing itself; and

(7) far enough away from the road so that approaching motor vehicles could be filmed over a road length of about 100 metres (in practice, this length varied between 55 and 199 m, with an average of 100.5 m across the sites; see Table 1).

In the selection procedure, compromises were made; the sixth requirement prevailed over the seventh. The sample of crossings selected is not intended to be representative of the universe of crossings in existence.

Table 1: Characteristics of the Sampled Crossings

	Location	Speed Limit (km/h)	Number of Tracks	Number of Lanes	Protection Type	Hourly Flow, Both Directions	Direction Observed	Far Zone Length (in m.)	Near Zone Length (in m.)
Kingston, Counter Street	Urban	50	2	2	Gates	699	NE	41.1	14.2
Oshawa, Wilson Street	Urban	50	2	2	Gates	461	N	28.3	41
Oshawa, Adelaide Street	Urban	50	3	4	FL&B	903	n.a*	n.a	n.a
Belleville, Dundas Street	Suburban	60	1	4	FL&B	540	W	27	31
Roblin, Highway 41	Rural	70	2	2	FL&B	241	S	75	59
Deseronto, Deseronto Road	Rural	80	2	2	Crossbucks	3	N	142	57
Marysville	Rural	80	2	1	Crossbucks	2	N	74.6	13

* n.a = not applicable

Table 1 summarizes the particulars of the seven railway crossings selected in this study. The speed limit refers to the posted or otherwise applying limit to road traffic. The hourly flow volumes of road traffic were the ones actually observed in this study; they refer to the total number of vehicles (i.e., lead **and** following vehicles) per hour travelling in **both** directions averaged across the numbers of observation hours at each crossing (see Table 7). The direction of the vehicular traffic that was included in the observation of speeds is also given in Table 1. This traffic was **unidirectional**. With respect to critical incidents, however, traffic in **both** directions was included in the observations.

Subjective estimation (by the present investigators) of crossing roughness and elevation was as follows: the Counter Street crossing in Kingston was relatively smooth, but it was at a noticeably higher elevation than the rest of the road. The Wilson Street crossing in Oshawa was relatively smooth and level with the roadway. The same held for the crossing on Adelaide Street in Oshawa. The Belleville crossing was by far the smoothest in the study and the tracks were virtually at exactly the same level as the road. The crossing near Roblin was quite rough, but level with the road. Southbound drivers approaching this crossing (i.e., the drivers observed) had just left the village of Roblin and were probably still accelerating through the far zone as well as part of the near zone. The crossing near Deseronto was at a slight elevation from the approaching road and somewhat rough. The crossing near Marysville (just west of Napanee) was situated on Wyman's Sideroad, a gravel road, and elevated above the road (essentially consisting of one lane only): it was the roughest crossing in the study sample.

The crossing located on Adelaide Street in Oshawa deserves special mention. It was included for the purpose of identifying critical events only, not for the systematic observation of approach speeds. This crossing does not lend itself to the latter, as approach traffic is encumbered by a nearby side street. It should be noted also that at this particular crossing train approach speed as well as the activation of the crossing signals was under the direct control of the train crew. There, the train was not supposed to proceed unless the train crew judged that road traffic was not endangered.

2.3 Apparatus

A JVC video camera, microphone and portable VCR recorder were used to record observations of vehicles in such a manner that vehicle moving speeds could be determined later. The camera equipment was battery powered, but could also be run from the cigarette lighter outlet of a vehicle (using an adaptor), so that records could be made without access to a stationary electrical outlet. A JVC editing VCR coupled to a JVC monitor was used to play back the video tapes so that specific data could be extracted or copied on another tape. A rented van was used to film from. This vehicle, a current-model, metallic-coloured Ford Econoline, looked much like an ordinary service vehicle and its use was intended to insure that the recording activity was inconspicuous and unobtrusive to naïve passers-by.

2.4 Quantitative Speed Measurement

For the purpose of quantitative speed measurement, naturally occurring landmarks which were clearly visible on the video screen (e.g., a telephone pole, a traffic sign, a tree stem) were used to demarcate two zones, one farther away from the crossing, and one close (see Figure 1).

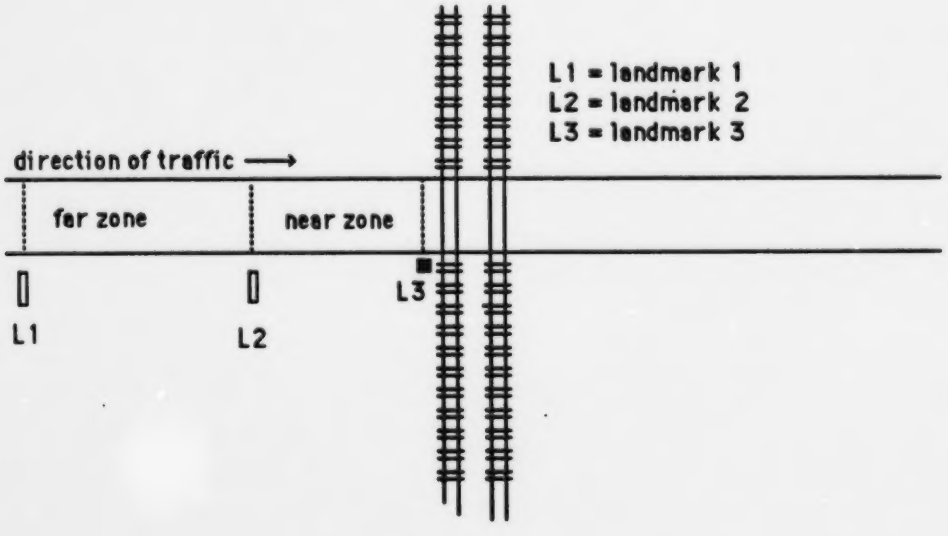

Figure 1. Diagram illustrating the method of speed measurements

The first zone (the "far zone" or Zone 1) was to represent the normal driving speed for the road leading to the crossing, and the second zone (the "near zone" or Zone 2) was to reflect any changes in behaviour, principally speed, that could be attributed to the presence of the rail crossing. For this reason, the upstream boundary of the near zone was as close to the crossing as possible, within the constraint of the availability of an already present landmark. The near zone was also kept as short as possible in order that the measured speed approximated the spot speed when the driver was very close to the crossing. Long near zones have the disadvantage that last moment changes in speed may be masked when

speeds are expressed as space-mean speeds and not as spot speeds. Space-mean speeds are defined as the ratio of the distance between two points and the time taken to cover that distance (Road Research Laboratory, 1965, p.107). The speed at which a single point is passed is referred to as spot speed.

The lengths of the two zones, which differed from crossing to crossing, were measured with a surveyor's measuring tape and are listed in Table 1.

A vehicle was selected for speed measurement when it was a lead vehicle while approaching the crossing. In other words, it was not closely following another vehicle. The actual criterion used was a temporal gap of a minimum of 5 seconds between the vehicle in question and any preceding vehicle as it exited from the near zone. All two-wheeled vehicles were excluded from this analysis (but included in the collection of critical incidents, as were all other road users).

The determination of whether a vehicle was a lead vehicle or not actually took place when the video tape was being played back on the monitor. By carefully stopping the tape just as a lead vehicle entered each of the two zones and by recording the time displayed in the upper left corner of the monitor, the time taken to negotiate each zone could be extracted with considerable precision. The division of this time by the measured length of the zone produced a zone speed in km/h. Descriptive statistics, including the mean, standard deviation, coefficient of variation, range, kurtosis and skewness were derived in order to characterize speed behaviour in each observation zone. These statistics were obtained for the aggregate lead vehicles as well as separately for three vehicle categories: (a) cars, (b) small trucks, including vans, pick-up trucks, (c) large vehicles, including tractor-trailers, buses and motor homes.

2.5 Collection of Train and Signal Data

At each crossing in the sample, the number of train approaches during the observation hours was noted, along with the durations of "warning time" as well as the "total signal durations." Warning time refers to the time lapse in seconds between the onset of the signal on the one hand and the actual arrival of the train at the crossing on the other. Total signal durations describe the time lapses between the onset and the cancellation of a signalling period. Descriptive statistics (means, standard deviations, etc.) were calculated for both temporal aspects of signal activation. The observation crew was also instructed to identify the occurrence and durations of false alarms, i.e., no train actually occupied the crossing in the time period between the onset and the cancellation of the crossing signals.

3. FINDINGS AND INTERPRETATIONS

3.1 Critical Incidents

A total of 65 critical incidents were seen during a total of 287 observation hours in which a total of 127 trains approached the crossings. So, critical incidents occurred in approximately one-half of the train approaches. If the crossings near Deseronto and near Marysville (the ones with very low vehicular volumes) are excluded from these calculations, the rate of critical incidents per warning period was 65 per 100 train arrivals, or about two-thirds. This rate is somewhat higher than in an earlier study at six railway crossings in Ontario (Wilde *et al.*, 1975, 1976). For individual crossings these rates were 31/41 in Kingston, 7/18 at the Wilson Street crossing in Oshawa, 15/28 at the Adelaide Street crossing, 9/9 in Belleville and 3/4 in Roblin. The denominators in these ratios differ slightly from the numbers of train arrivals in Table 6, due to the video equipment being installed, but not activated at the time the signals started (so that warning times could not be ascertained), but the observation crew was present at the site and turned on the camera in time to record the critical incident. The observed critical incidents are summarily described in Table 2. Reference to the relevant location in the video material is added in brackets.

In an effort to tentatively establish the factors underlying the occurrence of the diversified critical incidents, we have made the following classification of "scenarios."

Scenario A: At the moment the lights begin to flash, the driver is too close to the crossing to be able to come to a safe and comfortable stop before the crossing. The driver maintains or increases speed (example: Table 2, Critical incident A.4).

Scenario B: When the lights begin to flash, the driver is too close to the crossing to be able to come to a safe and comfortable stop before the crossing. Nevertheless, the driver brakes (example: Table 2, Critical incident A.21). (In the case of crossings with gates, the vehicle may make contact with a descending or descended gate.)

Scenario A-B: This is a mixed scenario of the two above; the driver oscillates between the decision to stop or not to stop (example: Table 2, Critical incident B.2).

Scenario C: When the lights begin to flash, the driver is far enough away to come to a safe and comfortable stop before the crossing, but the driver decides to continue on his (her) way (example: Table 2, Critical incident D.2).

Scenario D: The driver has first come to a halt before the crossing (with gates, or FL&B only), but subsequently decides to proceed despite the activated signals (example: Table 2, Critical incident D.5).

Scenario E: While the signals are activated or not (or there are no FL&B), some drivers approach the crossing at a much lower speed than the traffic behind. The danger of a rear-end collision is enhanced (example: Table 2, Critical incident A.17).

Table 2: Critical Incidents
(with reference to tape number and revolution)

A. Kingston, Counter Street (Gates)

1. After signal onset car crosses tracks (Tape 2, Rev. 484).
2. Same as above (Tape 2, Rev. 752).
3. A vehicle brakes, but does not stop in time and barrier hits vehicle (Tape 2, Rev. 1269).
4. Three cars cross after signal onset and a fourth backs up so that the barrier can fully descend (Tape 2, Rev. 4040).
5. Two cars cross after signal onset (Tape 3, Rev. 2697).
6. During a **false alarm**, a motor home crosses after signal onset and a jeep -- now at the head of the line -- makes a U-turn and leaves (Tape 3, Rev. 3107).
7. A car crosses tracks after signal onset (Tape 3, Rev. 3236).
8. Two cars cross after signal onset (Tape 3, Rev. 3745)
9. A car has to back up so barrier does not hit it after signal onset (Tape 3, Rev. 3961).
10. A car crosses after signal onset (Tape 3, Rev. 4027).
11. As above (Tape 4, Rev. 2365).
12. A van plus a car pulling a trailer cross tracks after warning starts (Tape 4, Rev. 2799).
13. A sports car and a van go across the tracks while barriers are down during a **false alarm** (Tape 4, Rev. 3312).
14. During a **false alarm**, a car crosses tracks after signal onset and then 2 bicyclists pull their vehicles under the barrier and proceed over the crossing (Tape 4, Rev. 3406).
15. A van crosses tracks after signal onset during a **false alarm** (Tape 4, Rev. 3821)
16. A truck crosses after signal onset (Tape 4, Rev. 4189).
17. While lights are not flashing, a car almost rear-ends a car moving very slowly towards the crossing (Tape 5, Rev. 1830).
18. During a **false alarm** period, 2 cars cross tracks after signal onset and a truck starts to drive around the barriers just before the latter start to rise (Tape 5, Rev. 3392).
19. Two cars go over crossing after signal onset (Tape 3, Rev. 1900).
20. A van crosses after signal onset (Tape 1, Rev. 1994).
21. A car comes to a screeching halt after signal onset and then is struck by a descending barrier (Tape 1, Rev. 1926).
22. During a **false alarm**, a lead car starts to back up just before the barriers are lifted (in an apparent attempt to zig-zag around them) (Tape 5, Rev. 4030).
23. During a **false alarm**, a lead car starts to drive around the barriers just before they go up (Tape 5, Rev. 4174).
24. A car crosses tracks after signal onset (Tape 6, Rev. 268).
25. During a **false alarm**, a car crosses over tracks after signal onset (Tape 6, Rev. 438).
26. A truck passes over crossing after signal onset (Tape 6, Rev. 964).
27. During a **false alarm**, a car goes over crossing after signal onset (Tape 6, Rev. 1284).
28. Two vehicles go over crossing after signal onset (Tape 6, Rev. 2347).
29. During a **false alarm**, a car crosses over tracks after signal onset (Tape 6, Rev. 2716).
30. A truck crosses track after signal onset (the driver of another truck coming from the other side apparently saw the approaching train and came to a stop before signal onset) (Tape 6, Rev. 2822).
31. During a **false alarm**, a van crosses over tracks after signal onset (Tape 6, Rev. 2897).

B. Oshawa, Wilson Street (Gates)

1. Two cars cross tracks after signal onset (Tape 14, Rev. 418).
2. Two cars cross tracks after signal onset, but the driver of the second car (apparently undecided as to what to do) first brakes and then proceeds through the crossing (Tape 3, Rev. 2030).
3. A truck crosses tracks after signal onset (Tape 13, Rev. 3210).
4. A car crossed tracks after signal onset (Tape 13, Rev. 3507).
5. Two cars drive between the barriers while these are down, and two other cars make U-turns and leave the line-ups at the crossing (the warning time was 3 minutes and 26 seconds!) Tape 13, Rev. 3700).
6. Two cars cross after signal onset (Tape 13, Rev. 3790).
7. Two vehicles cross after signal onset (Tape 13, Rev. 4175).

C. Oshawa, Adelaide Street (Flashing lights and bells)

1. Two cars cross after signal onset (Tape 11, Rev. 1979).
2. A car screeches to a halt after signal onset and is almost rear-ended by the car behind (Tape 11, Rev. 2032).
3. Five eastbound and 2 westbound cars cross tracks after signal onset, with the train stopped within sight just south of the crossing (Tape 11, Rev. 2480).
4. Signal starts while cars are stopped on the crossing waiting for the traffic light at the next intersection to change (Tape 11, Rev. 2530).
5. After signal onset and the train is in motion only metres from the crossing, a westbound car "flies" across the tracks (Tape 11, Rev. 2570).
6. With signal on and immobile train partially blocking eastbound traffic, seven westbound vehicles cross over tracks (Tape 11, Rev. 2400).
7. One westbound car crosses tracks after signal onset and an eastbound motorcycle goes through the crossing before the train is completely out of the crossing (Tape 19, Rev. 2180).
8. Two westbound vehicles cross tracks after signal onset (Tape 19, Rev. 2220).
9. Two eastbound vehicles cross tracks after signal onset (Tape 19, Rev. 2790).
10. Two eastbound and two westbound vehicles cross tracks after signal onset (Tape 19, Rev. 2830).
11. Two eastbound and one westbound vehicle cross tracks after signal onset (Tape 19, Rev. 3180).
12. One westbound vehicle crosses tracks after signal onset (Tape 19, Rev. 3390).
13. One car crosses tracks after signal onset, another screeches to a halt, and a motorcycle switches lanes to pass the stopped vehicle and proceeds through the crossing (all vehicles eastbound) (Tape 19, Rev. 3450).
14. Two westbound vehicles cross tracks after signal onset (Tape 19, Rev. 3570).
15. One eastbound car crosses tracks after signal onset (Tape 19, Rev. 3595).

D. Belleville, Dundas Street (Flashing lights and bells)

1. After signal onset, two cars cross tracks westbound and seven eastbound (Tape 16, Rev. 1370).
2. After signal onset, seven vehicles westbound (including one ambulance) and nine vehicles eastbound cross tracks (Tape 16, Rev. 1730).
3. After signal onset, a westbound car stops before crossing and then proceeds to go across (Tape 16, Rev. 1790).
4. After signal onset, four westbound vehicles cross tracks. The first did not even slow down, and the last must have surely seen the train approaching. In addition, four eastbound vehicles cross after signal onset (Tape 16, Rev. 2200).
5. After signal onset, three westbound vehicles cross tracks, each of which had stopped before crossing and proceeded to go across. In addition, one eastbound vehicle crosses after signal onset (Tape 16, Rev. 2880).
6. Three westbound vehicles and two eastbound cross tracks after signal onset (Tape 16, Rev. 3840).
7. After signal onset, 5 westbound cars slow and then proceed across the tracks. The driver of a sixth westbound vehicle passes the warning post, sees the train coming, stops just before the actual track and backs up. One eastbound vehicle crosses tracks after signal onset (Tape 18, Rev. 2195).
8. After signal onset, two cars cross tracks without slowing down. A third car comes to a complete stop. The van behind it changes lanes to get around the stopped car. The van driver then looks both ways and crosses the tracks. Six eastbound vehicles cross after signal onset (Tape 18, Rev. 3700).

E. Roblin, Highway 41 (Flashing lights and bells)

1. After signal onset one car crosses the tracks, drivers of three more cars come to a complete stop, look for the train and then go over the crossing (Tape 7, Rev. 1043).
2. A motorcycle crosses the track after signal onset (Tape 8, Rev. 2884).
3. After signal onset, a van goes across the track and a second vehicle stops (the driver presumably looks for the train) and then goes across (Tape 8, Rev. 4220).

F. Deseronto and Marysville (Crossbucks only)

No critical incidents seen.

Table 3: Speeds in the Far Zone (in km/h)

	Number of Lead Vehicles	Mean	Min.	Max.	S.D.	C.V.	Skew	Kurtosis
Kingston, Counter Street	537	63.52	32	95	10.48	0.16	0.22	0.26
Cars	332	64.58	32	95	10.31	0.16	0.18	0.43
Small trucks	136	64.42	36	95	10.15	0.16	0.27	0.02
Large vehicles	69	56.66	33	85	9.41	9.17	0.55	1.18
Oshawa, Wilson Street	692	66.99	23	102	11.29	9.17	-0.07	0.68
Cars	434	67.73	28	102	10.39	0.15	0.10	1.20
Small trucks	223	67.69	36	102	11.47	0.17	0.03	-0.29
Large vehicles	35	52.84	23	78	11.78	0.22	-0.10	-0.03
Belleville, Dundas Street	575	72.51	34	122	15.75	0.22	-0.17	-0.11
Cars	421	72.76	36	122	15.28	0.21	-0.02	-0.08
Small trucks	133	73.49	34	122	16.46	0.22	-0.44	-0.15
Large vehicles	21	61.37	34	88	17.00	0.28	-0.33	-0.14
Roblin	741	64.05	40	96	9.27	0.15	0.32	0.10
Cars	500	64.37	40	96	9.34	0.15	0.04	0.25
Small trucks	177	63.51	42	82	8.62	0.14	-0.03	-0.46
Large vehicles	64	63.32	43	90	10.38	0.16	0.36	-0.29
Deseronto	40	89.67	50	142	22.97	0.26	0.57	-0.28
Cars	23	92.52	59	142	21.72	0.23	0.68	-0.12
Small trucks	17	85.80	50	136	24.70	0.29	0.59	-0.44
Marysville	19	39.58	25	60	8.63	0.22	0.39	-0.14
Cars	5	40.68	32	48	7.26	0.18	-0.18	-0.67
Small trucks	9	41.30	25	60	11.00	0.27	-0.04	-0.71
Large vehicles	5	35.36	33	41	3.18	0.09	1.09	-0.36

Table 4: Speeds in the Near Zone (in km/h)

	Number of Lead Vehicles	Mean	Min.	Max.	S.D.	C.V.	Skew	Kurtosis
Kingston, Counter Street	537	18.12	10	34	3.45	0.19	0.62	0.90
Cars	332	18.52	11	34	3.43	0.19	0.72	1.06
Small trucks	136	18.17	10	30	3.40	0.19	0.56	0.63
Large vehicles	69	16.06	10	24	2.91	0.18	0.34	-0.23
Oshawa, Wilson Street	692	62.95	30	98	10.11	0.16	0.24	0.30
Cars	434	63.11	30	92	9.35	0.15	0.27	0.22
Small trucks	223	63.76	41	98	10.59	0.17	0.43	0.16
Large vehicles	35	51.96	31	74	10.05	0.19	0.10	-0.58
Belleville, Dundas Street	575	65.18	32	112	12.66	0.19	0.15	0.42
Cars	421	65.17	32	112	12.14	0.19	0.26	0.43
Small trucks	133	66.57	33	112	13.65	0.21	-0.02	0.47
Large vehicles	21	56.52	34	74	13.39	0.24	-0.17	-1.40
Roblin	741	54.37	27	97	11.42	0.21	0.45	-0.02
Cars	500	54.56	30	97	11.50	0.21	0.53	0.04
Small trucks	177	54.63	33	79	10.31	0.19	0.08	-0.58
Large vehicles	64	52.25	27	88	13.46	0.26	0.65	0.14
Deseronto	40	49.57	23	108	16.52	0.33	1.41	2.72
Cars	23	49.42	23	108	19.90	0.40	1.43	1.80
Small trucks	17	49.76	34	71	10.99	0.22	0.23	-0.65
Marysville	19	20.89	12	29	5.27	0.25	-0.08	-1.06
Cars	5	20.87	14	25	4.23	0.20	-1.07	-0.26
Small trucks	9	23.14	16	29	5.03	0.22	-0.15	-1.47
Large vehicles	5	16.87	12	25	5.01	0.30	0.66	-0.80

Scenario F: Signals start to flash while road traffic is stopped (stalled, backed up) on the crossing (example: Table 2, Critical incident C.4).

While Scenarios A and B typify **a driver's inability to obey the signal**, Scenarios C and D, in contrast, reflect a driver's **unwillingness** to obey the signal. No systematic attempt has been made to allocate each of the observed critical incidents to one or more of the above scenarios and to quantify the relative frequency of the latter. This is because such allocation would be highly speculative in nature. No data were collected in the present study as to what the driver actually perceived and when, nor why a particular decision was taken (the collection of such data would have demanded a very different methodology). Thus, it is difficult to determine whether a particular incident is an example of either Scenario A or C. Both Scenarios A and C are also difficult to distinguish from yet another possibility: the driver is unaware of the fact that he or she is approaching a railway crossing and/or of the flashing signals.

Moreover, some scenarios are possible at some crossings only and not at others. Scenarios A through D can only occur provided there are active signals at the crossing in question, not at crossings equipped with crossbucks only. Scenario F is more likely at crossings in urban locations (because of traffic density), especially when signal operation is under the manual control of the train crew (cf. a flagman) and thus a train is not supposed to enter the crossing unless it is clear (thereby reducing the consequences as perceived by the driver). Therefore, any aggregate frequency count would be highly sensitive to the characteristics of the particular crossings sampled for observation.

Nonetheless, inspection of Table 2 suggests that Scenario D (reflecting unwillingness to obey the signals) was particularly common at the Kingston and Belleville crossings. The Kingston crossing was the only one to show a high incidence of false alarms (i.e., about one-third of all observed alarms; see Tables 6 and 7) and the Belleville crossing had the highest average warning time (see Table 6) of all crossings in the present sample.

3.2 Data on Vehicular Speeds in the "Far Zone" and the "Near Zone"

Tables 3 and 4 present summaries of the speed data collected in the far and in the near zones. Along with means and standard deviations, the minima and maxima are also listed. The range of speed at any individual crossing was found to be very great, especially in the far zone. For instance, the difference between the fastest and the slowest vehicle in this zone amounted to 63 km/h at the Kingston crossing, to 79 km/h at the Wilson Street crossing in Oshawa, to 88 km/h at the Belleville crossing, and at the Roblin crossing the fastest vehicle moved 56 km/h faster than the slowest.

A comparison of average speed in the **far zone** and the posted speed limit shows that at the Kingston crossing drivers moved on average about 13.5 km/h faster than the limit; in Oshawa they exceeded the limit on average by 17 km/h; the analogous value for the Belleville crossing was 12.5 km/h; while at the Roblin crossing average speed was about 6 km/h lower than the posted speed limit.

Table 5: Speed Change from the Far Zone to the Near Zone (in km/h)

	Number of Lead Vehicles	Correlation**	Mean	S.D.	C.V.	Skew	Kurtosis
Kingston, Counter Street	537	0.61	45.41	8.79	0.19	-0.10	0.33
Cars	332	0.58	46.06	8.77	0.19	0.00	0.65
Small trucks	136	0.64	46.25	8.41	0.18	-0.19	-0.25
Large vehicles	69	0.53	40.60	8.23	0.20	-0.58	0.78
Oshawa, Wilson Street	692	0.86	4.24	5.84	1.38	-0.13	1.45
Cars	434	0.85	4.62	5.51	1.19	-0.17	0.65
Small trucks	223	0.84	4.03	6.34	1.57	-0.29	1.85
Large vehicles	35	0.88	5.54	6.32	1.14	1.42	3.24
Belleville, Dundas Street	575	0.89	7.33	7.33	1.00	-0.46	1.72
Cars	421	0.87	7.59	7.55	1.00	-0.55	1.99
Small trucks	133	0.92	6.92	6.59	0.95	0.06	-0.10
Large vehicles	21	0.92	4.85	7.14	1.47	-0.14	-0.66
Roblin	741	0.81	9.68	6.72	0.69	-0.23	1.30
Cars	500	0.80	9.78	6.87	0.70	-0.02	1.20
Small trucks	177	0.82	8.88	5.94	0.67	-0.68	1.72
Large vehicles	64	0.84	11.07	7.36	0.66	-0.66	0.80
Deseronto	40	0.40	40.10	22.24	0.55	-0.18	-0.75
Cars	23	0.45	43.10	21.98	0.51	0.23	-0.91
Small trucks	17	0.41	36.04	22.60	0.63	-0.74	0.07
Marysville	19	0.82	18.69	5.28	0.28	-0.33	0.30
Cars	5	0.75	19.81	4.93	0.25	0.91	-0.50
Small trucks	9	0.91	18.16	6.77	0.37	-0.39	-0.49
Large vehicles	5	0.88	18.50	2.65	0.14	-0.41	-1.83

Table 6: Warning Time Durations (in seconds)

	Protection	Observation Hours	Number of Train Arrivals	Warning Times (in seconds)				
				Shortest	Longest	Mean	S.D.	C.V.
Kingston, Counter Street	Gates	88	41	13	71	34	11	0.34
Oshawa, Wilson Street	Gates	26	18	22	206	38	42	1.11
Oshawa, Adelaide Street	FL&B	8	28	3	28	15	7	0.46
Belleville, Dundas Street	FL&B	35	5	45	105	23	24	0.32
Roblin	FL&B	38	4	39	129	58	40	0.68
Deseronto	Crossbucks	62	3	n.a.	n.a.	n.a.	n.a.	n.a.
Marysville	Crossbucks	30	28	n.a.	n.a.	n.a.	n.a.	n.a.

n.a. = not applicable

Variations between speeds in the **near zone** were found to be very marked at each of the crossings, as may be seen from Table 4. In this zone the average speed at the Kingston crossing was well below the posted speed, in Oshawa (Wilson Street) it exceeded the speed limit by about 13 km/h and at the Belleville crossing by about 5 km/h.

3.3 Comparisons Between Vehicular Speeds in the Far and Near Zones

From a comparison of the corresponding columns in Tables 3, 4 and 5, we have, with some exception, not been able to detect much of a consistent pattern. When the three categories of vehicles approaching the same crossing are compared, a drop in speed from the far zone to the near zone is observed on average. However, in some cases, the coefficient of speed variation is higher in the far zone and in some cases it is smaller, the total number of these cases being about equal.

Although this fails to add support to the earlier findings of a progressively greater coefficient of speed variation (Wilde *et al.*, 1975, 1976), it should be borne in mind that the method of delineating zones and zone lengths was quite different in that previous study. Earlier, there were four distinct zones on the road toward each actual crossing and each zone measured exactly 50 feet (15.24 m) at each crossing. In the present study, only two zones were considered and -- depending upon the crossing -- the far zones varied between 27 and 142 m in length and the near zones between 13 and 59 m (see Table 1). In other words, the zoning procedure (due to the relatively long near zones) was less sensitive to the actual speeds of vehicles in the last 15 m just before entering the crossing.

Whatever the implications of this may be for the interpretation of the present (as compared to the earlier) findings, it can be seen from Table 5 that drivers at four of the six crossings (Kingston, Oshawa, Belleville, Roblin) showed a much greater coefficient of variation in **speed reduction** than they did in their speeds in either the far or the near zone. (In the remaining two crossings with low vehicular volumes -- Deseronto and Marysville -- these coefficients were roughly of the same size.) In other words: while approaching these crossings, drivers showed much greater within-driver variability in their between-zone speed change than they did in their between-driver speed within each zone. As most coefficients in the skewness column in Table 5 are negative, it follows that most drivers slowed down by a relatively modest amount, while a considerable minority reduced speed by a very large degree (in fact, by so much that they had a "disproportionate" effect upon average speed reduction).

This pattern of findings is illustrated by Figures 2 through 7. These curves pertain to all drivers (aggregated across the three categories of vehicles; the values along the vertical axes indicate percentages of the total samples) and all curves lean toward the left (i.e., show negative skewness), indicating that the mean speed reduction is greater than the median speed reduction. Moreover, four of these curves (Figures 2, 3, 4 and 5) show that some drivers at some crossings (Oshawa, Belleville, Deseronto and Roblin) either did not slow down at all as they were approaching the crossing concerned (i.e., while moving from the far to the near zone), but even increased speed. In some cases, especially the Oshawa and Belleville crossings, this may have been due to traffic that had just joined the road in question, or was moving toward "the open road" with a higher posted speed limit and thus had not yet attained its target or "normal" speed.

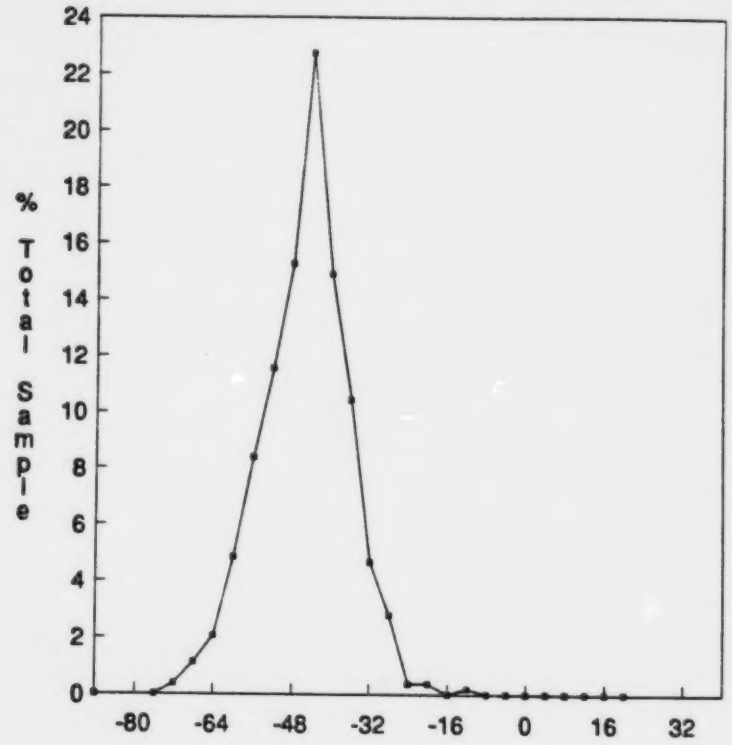

Figure 2

Speed change distribution at Kingston (speed in far zone subtracted from speed in near zone). Percentage of total sample plotted on vertical axis.

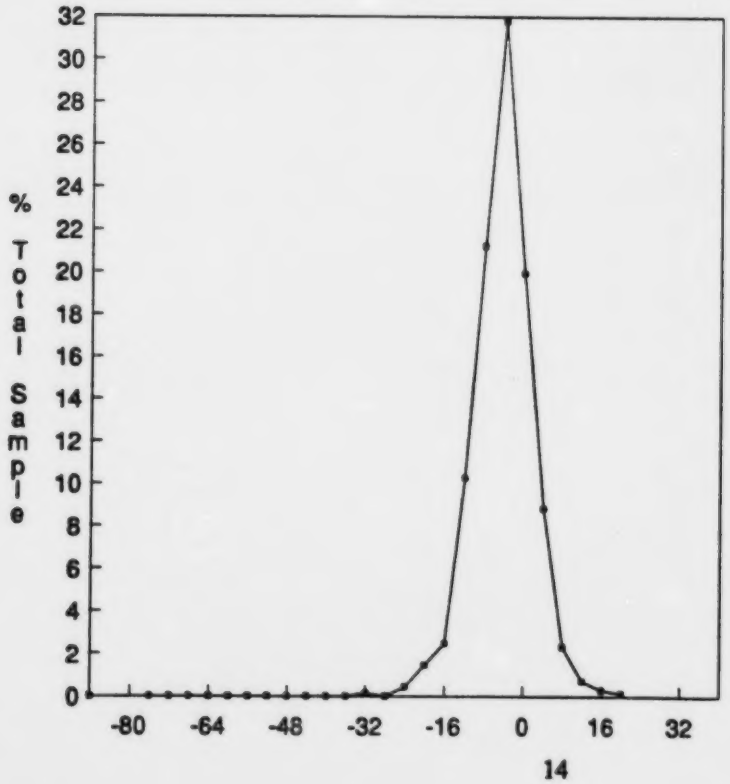

Figure 3

Speed change distribution at Wilson Street in Oshawa (speed in far zone subtracted from speed in near zone). Percentage of total sample plotted on vertical axis.

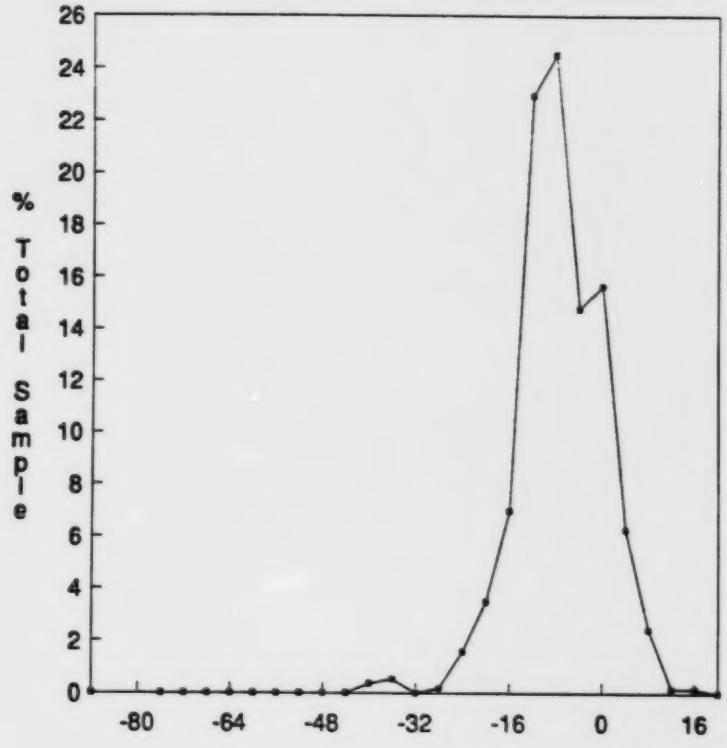

Figure 4

Speed change distribution in Belleville (speed in far zone subtracted from speed in near zone). Percentage of total sample plotted on vertical axis.

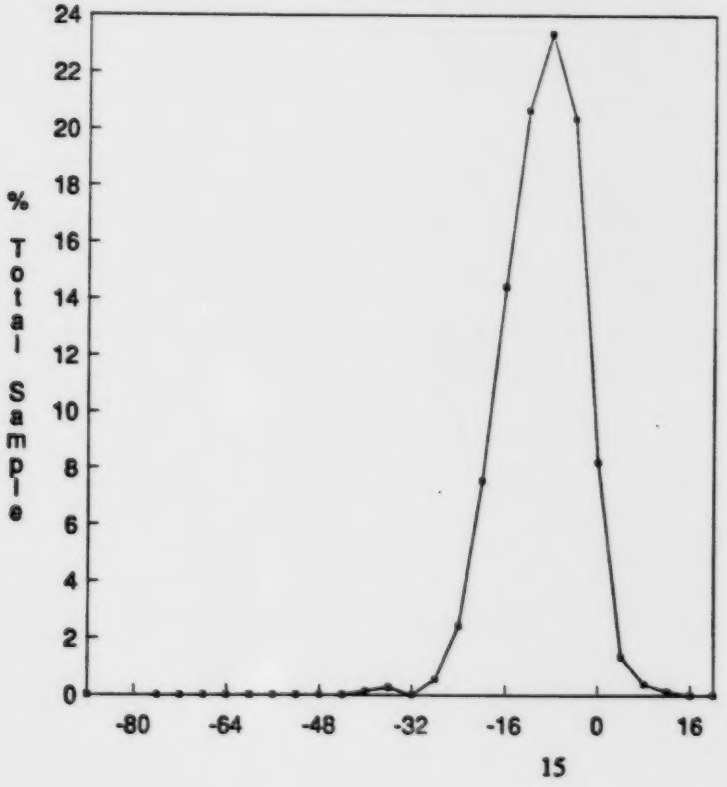

Figure 5

Speed change distribution in Roblin (speed in far zone subtracted from speed in near zone). Percentage of total sample plotted on vertical axis.

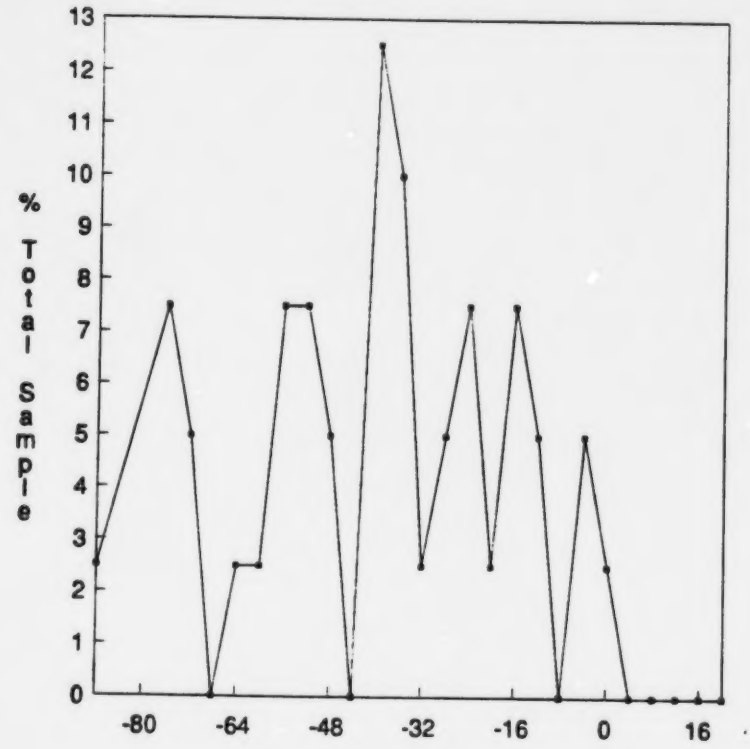

Figure 6

Speed change distribution in Deseronto (speed in far zone subtracted from speed in near zone). Percentage of total sample plotted on vertical axis.

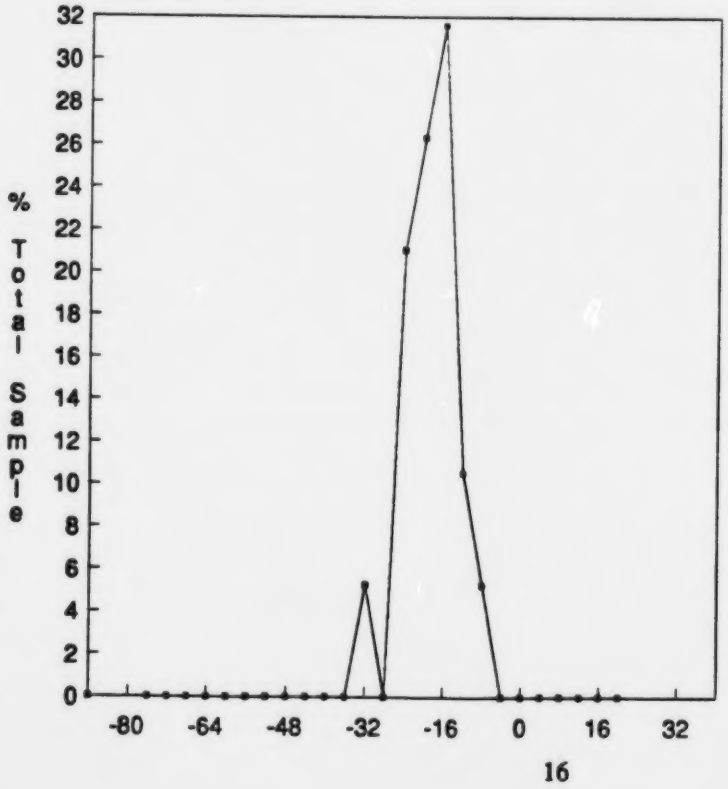

Figure 7

Speed change distribution in Marysville (speed in far zone subtracted from speed in near zone). Percentage of total sample plotted on vertical axis.

3.4 Data on Warning Times

Warning times are defined as the time span between the activation of the warning signal and the train entering the crossing. These are presented in Table 6, which shows that there were considerable differences both within and between crossings in the time lapse between the onset of the signal and the actual arrival of the train on the crossing surface.

Average warning times were the longest average at the Belleville crossing (i.e., one minute and 13 seconds); the shortest observed warning time at that crossing being as long as 45 seconds. The greatest variability from one signalling period to another at the same crossing was observed at the Wilson Street crossing in Oshawa (c.v.=1.11). The extremely short minimum warning time observed at the Adelaide Street crossing in Oshawa should be understood in the context of the kind of crossing protection prevailing at that particular crossing; no train is supposed to enter the crossing unless the train crew judges it safe. The very short minimum warning time that occurred at the Kingston crossing (13 seconds) is, however, of a totally different origin. It occurred immediately following a false alarm. The average duration of warning times that immediately followed the false positive signal activations was 17.9 seconds, the longest lasted 25 seconds.

3.5 Data on False Alarms and Total Signal Durations

From Table 7 it can be seen that false alarms in the present study occurred only at one of the crossings selected, but there they occurred quite often, in 21 of 41 alarm periods observed. In fact, these false alarms occurred invariably when an eastbound passenger train approached the station (a few hundred metres west of the crossing). While such a train was approaching the station, the crossing lights were activated and the gates descended. However, each such train stopped at the crossing to allow passengers to leave and mount and at some point in time while the train was stopped the signals were deactivated, to be activated again when the train left the station and moved toward the crossing. The shortest among the 21 observed false alarms lasted 2 minutes and 11 seconds, the longest 2 minutes and 46 seconds. The average duration was 2 minutes and 37 seconds (standard deviation 9.97, coefficient of variation 0.06). They were thus remarkably constant in length. (These time durations, as far as they pertain to false alarms, are not tabulated in Table 7).

Table 7: False Alarms, Critical Incidents (in numbers) and Total Signal Durations (in seconds)

	Number of Train Arrivals	Number of False Alarms	Critical Incidents	Warning Times (in seconds)				
				Shortest	Longest	Mean	S.D.	C.V.
Kingston, Counter Street	41	21	31*	33	156	66	23	0.34
Oshawa, Wilson Street	18	none	7	39	308	76	83	1.08
Oshawa, Adelaide Street	28	none	15	28	263	83	61	0.74
Belleville, Dundas Street	5	none	9	99	274	167	99	0.60
Roblin	4	none	3	49	493	202	198	0.98
Deseronto	3	n.a.	0	n.a.	n.a.	n.a.	n.a.	n.a.
Marysville	28	n.a.	0	n.a.	n.a.	n.a.	n.a.	n.a.

* Note that a false alarm is not counted as a critical incident, nor included in the signal duration data.
n.a. = not applicable

While false alarms were not counted as critical incidents *per se*, critical incidents occurring **during** false alarm periods were considered to be just that (see Table 2). For one thing, some drivers may not have been fully aware of the falseness of the alarm created by the eastbound passenger train, and for another, a westbound train might have been approaching the crossing during such a period (although the latter never happened during the present observations). Moreover, there was the theoretical possibility of an eastbound freight train passing the stopped passenger train on the other track (thereby likewise defalsifying the alarm originally triggered by the eastbound passenger train, but this possibility did not materialize either in the course of the present data collection).

False alarms, like unduly long warning times, are pernicious events, but probably even more so. They undermine the credibility of railway signals at the location where these false alarms occur and lack of confidence in the signals is likely to generalize to locations where an individual driver has not experienced one. False alarms provoke drivers to decide for themselves whether it is safe to cross, and in doing so they may make a catastrophic error.

Total signal durations (see Table 7) were measured from the onset to the cancellation of the flashing signal. These durations are comprised of the warning times and the durations of train occupancy of the crossing. Major variations between crossings were found. The shortest, at the Belleville crossing, was as long as 99 seconds, the longest as long as 8 minutes and 13 seconds at the Roblin crossing. The Wilson Street crossing in Oshawa showed the greatest variation in total signal duration from one alarm period to another (c.v.=1.08). The significance of total signal duration for driver behaviour is located in the fact that the longer it is, the greater the pressure drivers will feel to negotiate the crossing before the train occupies it. Long total signal durations foster the tendency to try to "beat the train to the crossing" and to wilfully disobey the signal in the first seconds after its onset (Leibowitz, 1983). It is likely that this tendency will generalize to a driver's approach behaviour at crossings other than where extremely long total signal durations have been personally experienced.

3.6 Vehicle Approach Speeds During a Railway Strike as Compared to Normal Conditions

Vehicular traffic during the strike was observed during 8 hours at the Kingston crossing and for 6 hours at the one in Belleville.

Weather conditions (no actual precipitation) were the same as during the "normal" (i.e., no strike) condition. Under both conditions approach speeds and approach speed changes were calculated from the video records while the crossing signals were not activated (see Table 8).

The only external (independent) variable consisted in the fact that during the strike the signals could not possibly be activated while the drivers were approaching the crossing, whereas they might under normal conditions. Thus, the comparison of driver behaviour between strike and no-strike conditions offered an opportunity to study the effect caused by the drivers' subjective estimation of the likelihood that the signals might come on while they were approaching the crossing. This subjective estimate would be expected to have been considerably reduced during the strike (although there is no assurance that all approaching drivers were cognizant of the strike and/or that it was still in effect when they were being observed).

Table 8: Speeds and Speed Reduction from the Far to the Near Zone During the 1987 Railway Strike

		Number of Lead Vehicles	Mean	Min.*	Max.	S.D.	C.V.	Skew	Kurtosis	** Correlation
Kingston	*Far Zone*	299	67.53	36	109	11.49	0.17	0.60	0.74	
	Cars	186	69.21	36	109	11.51	0.17	0.63	1.16	
	Small trucks	74	66.87	48	95	10.91	0.16	0.57	-0.17	
	Large vehicles	39	60.81	42	85	10.05	0.17	0.65	-0.03	
	Near Zone	299	19.96	12	37	4.40	0.20	0.66	0.76	
	Cars	186	20.40	12	37	4.42	0.21	0.73	0.78	
	Small trucks	74	19.78	12	30	3.51	0.18	0.35	0.05	
	Large vehicles	39	18.22	12	26	3.57	0.20	0.24	-1.00	
	Speed Reduction	299	47.57	23	63	9.13	0.19	-0.54	0.54	0.70
	Cars	186	48.80	23	77	8.99	0.18	-0.41	0.54	0.72
	Small trucks	74	47.09	31	74	9.18	0.20	-0.83	1.08	0.61
	Large vehicles	39	42.59	27	63	8.07	0.19	-0.70	0.11	0.68
Belleville	*Far Zone*	291	76.64	36	122	15.89	0.21	-0.41	-0.20	
	Cars	206	75.95	36	108	15.28	0.2	-0.47	-0.33	
	Small trucks	74	79.11	39	122	16.95	0.21	-0.28	-0.07	
	Large vehicles	11	72.98	39	92	19.28	0.26	-0.72	-0.90	
	Near Zone	291	66.32	34	93	12.69	0.19	0.08	-0.34	
	Cars	206	65.27	36	93	11.51	0.18	0.17	-0.50	
	Small trucks	74	69.93	34	93	14.97	0.21	-0.32	-0.25	
	Large vehicles	11	61.66	41	86	13.11	0.21	0.09	-0.50	
	Speed Reduction	291	10.32	-17	28	9.78	0.95	-0.14	-0.33	0.79
	Cars	206	10.68	-17	36	9.95	0.93	-0.18	-0.28	0.76
	Small trucks	74	9.18	-11	28	9.34	1.02	0.02	-0.58	0.84
	Large vehicles	11	11.31	-2	30	9.62	0.85	-0.13	-0.95	0.89

* negative values indicate speed increases

** i.e., product-moment correlation between the same-vehicle speeds in the far and the near zone

Analyses of variance of speeds were conducted for all vehicles combined and separately for each of the three vehicle categories at both crossing sites. The relevant data were those tabulated in Tables 3, 4, 5 and 8 as far as the two crossings are concerned.

With respect to the far zone at the Kingston crossing, it was found that the aggregate of all vehicles moved faster (by about 4 km/h) under the strike condition. This is statistically significant with a chance probability, $p<.001$. [What this means is that the probability of the observed speed change occurring by chance is less than one in a thousand.] The same was observed (see Table 8) for each of the three subcategories (cars about 4.6 km/h faster, $p<.001$; small trucks about 2.5 km/h faster, $p<.11$; and large vehicles about 3.9 km/h faster, $p<.034$). Observation in the near zone at this crossing showed a similar pattern. The aggregate of vehicles moved significantly faster (by about 1.8 km/h) in the strike condition ($p<.001$). The same was true for cars (by about 1.8 km/h, $p<.001$), for small trucks (by about 1.9 km/h, $p<.001$) and for larger vehicles (by about 2.1 km/h, $p<.001$).

In the far zone at the Belleville crossing, the average speed of all vehicle categories combined was higher during the strike (by about 4.1 km/h; the difference being statistically significant, $p<.001$). Cars moved about 3.2 km/h faster ($p=.01$), small trucks about 5.6 km/h ($p=.02$) and large vehicles 11.6 km/h faster ($p=.09$). At the same time, the average

speed in the near zone was about 1.1 km/h higher during the strike (all vehicles combined, $p<.25$), about 0.1 km/h higher for cars ($p=.9$), about 3.4 km/h higher for small trucks ($p=.1$) and about 5.1 km/h for large vehicles ($p=.3$). All of the above p-values are two-tailed.

Speed reduction (i.e., the space-mean speeds in the near zone subtracted from the space-mean speed in the far zone) at the Kingston crossing was, in statistical terms, significantly greater during the strike than under normal conditions (by about 2.2 km/h, when all vehicle categories are considered in combination, $p<.001$). Separate values for cars were 2.7 km/h ($p=.11$), 0.7 km/h for small trucks ($p=.5$) and 2 km/h for large vehicles ($p=.2$). Analogous data for the Belleville crossing were, respectively: average speed reduction across all vehicle categories 3 km/h (p,.001), for cars 3.1 km/h (p,.001), for small trucks 2.3 km/h ($p=.04$), and 6.5 km/h ($p=.03$) for large vehicles. So, during the strike, drivers moved faster in the far zone and, although they applied more speed reduction from the far to the near zone, they also drove faster in the near zone.

It would seem reasonable to infer from these data that drivers' approach speeds in the far as well as in the near zones are in fact influenced by their estimate of the likelihood that the signals might be activated during their approach. When this subjective likelihood is small, they move faster in both the far and the near zones. It should, however, be noted that our unplanned experimental design was a rather incomplete one; no data were collected at crossings where the strike did not apply (it was a national one), nor are any data presently available to show that speeds after the termination of the strike returned to pre-strike levels.

4. DISCUSSION

As stated in the Introduction, the primary objective of the present study was to explore the feasibility of video recording for the identification of critical incidents at level railway crossings. From the analysis of the records collected, it would seem that this exploration was successful. Critical incidents were easily identified from the video records and did seem to present less ambiguity than would be expected to occur in written or oral narratives. These records are now ready to be selected and compiled for visual communication to interested parties.

As regards the second objective, it would seem clear as well that video records of vehicle volumes and speeds while approaching railway crossings lend themselves adequately to quantitative analysis. It should be noted, however, that the video records as collected in the present study did not allow the (approximate) identification of driver sex, age or head movements (indicative of driver visual search) as were observed in some previous research (Wilde *et al.*, 1975,1976). Future use of several simultaneously synchronized cameras focussing upon the approach road and the crossing itself may be able to mimic sensitivity, speed of movement, and adaptability, if not the intelligence of the human eye.

The substantive findings and interpretations made in this investigation can be summarized as follows:

(1) Critical incidents, as defined in the present study, are very common events. They occurred in about two-thirds of the periods of signal activation at crossings with high traffic volume (see Section 3.1). There is, therefore, no justification for attributing the phenomenon of road users entering the crossing after signal onset to a small minority of atypical individuals (Wilde *et al.*, 1975, 1976; Wigglesworth, 1979).

(2) Some drivers (the exact number cannot be determined) entered the crossing after signal onset because they were too close to be able to come to a safe stop in front of the crossing (see Section 3.1).

(3) Some drivers braked abruptly after signal onset, because they were too close at signal onset to come to a more gradual, safe and comfortable stop before the crossing (see Section 3.1).

(4) Some drivers and other road users were deliberate in entering the crossing after signal onset, as they had sufficient time to stop (and they did either stop or reduce speed gradually) before the crossing (see Section 3.1).

(5) In periods in which the signals were not activated, there was marked heterogeneity in between-driver approach speeds (see Section 3.2).

(6) When the signals were not activated, the average approach speed of lead vehicles at some distance from and/or close to the crossing was higher than the posted speed limit at some crossings and lower at others (see Section 3.2).

(7) When signals were not activated, drivers were found to display a greater variation in speed change between an area more remote from a crossing to an area closer to it than they did in their choice of speed in either area. At most crossings, the majority

of approaching drivers slowed down by a relatively modest amount, while a considerable minority reduced speed by a very large degree. Some drivers, however, did not slow down at all, but maintained speed or even increased it (see Section 3.3).

(8) In contrast to earlier studies, the coefficients of speed variation (when the signals were not activated) were not markedly higher on the roadway very close to the crossing as compared to a zone at some distance from the crossing. This discrepancy between earlier and present findings was attributed to differences in the zoning method (see Section 3.3). The correctness of this explanation could, in fact, be verified by replaying the videotapes with artificial markers on the screen itself (as distinct from the picture) so that zones of any length and number can be chosen. (This possibility, parenthetically, highlights a major advantage of video records.)

(9) Warning times (i.e., the time lapse between the onset of the signals and the actual arrival of the train at the crossing) were found to vary a great deal both at the same crossing and when the averages between different crossings were compared. The shortest warning time at crossings with automatic warning devices observed in the present study was 13 (thirteen) seconds, the longest 73 seconds (see Section 3.4).

(10) The time lapses between the onset and cancellation of flashing lights (i.e., total signal durations) were also seen to vary greatly, both within and between crossings with automatic signals. The longest such time lapse observed exceeded 8 minutes, while the shortest took 28 seconds (see Table 7). The average time loss to drivers due to signal activation varied, depending upon the crossing, between 66 and 202 seconds per train arrival at signalized crossings.

(11) False alarms were seen at only one crossing in the present study, but there they were common events. They occurred every time an eastbound passenger train stopped at a station just west of the crossing location. Per 24-hour period there were, according to the passenger-train schedule, ten such trains at the time of study, so there were ten false alarms per day. Twenty-one of these false alarms were actually seen by the observation crew in the present study. Their average duration was 157 seconds and they ranged between 131 and 166 seconds. They were thus remarkably constant in length and fully predictable (i.e., to an informed observer).

(12) During the railroad strike, it was found that drivers' approach speeds at two selected crossings were higher than under normal conditions. The effect was observed both farther away from and closer to the crossings concerned and explained as due to drivers choosing a higher approach speed when their subjective estimate of the likelihood of signal onset is low.

Many of the problems (accidents, critical incidents, high speed variation) that occur at railway crossings would seem to arise from the following main sources.

Some drivers are not aware they are approaching a crossing or are not aware of a train already or soon to be on it. A Japanese study estimated that this factor was responsible for about one-third of train-vehicle collisions (Ikeda, 1971). On the basis of an American study (Schoppert and Hoyt, 1968), an estimate of about one-fourth may be derived (Wilde, *et al.* 1975, 1976; Hauer and Wilde, 1987). Unawareness of train approach may be comparatively

common at crossings that are rarely used by trains, or rarely at the time of day at which a driver is approaching (a train thus not being expected by the driver).

Some of those who are in fact aware they are approaching a crossing as well as of the activated signals may meet with the **"unobeyable signal problem"**: the signals begin to flash at a moment of time at which the driver (given his or her speed and distance downstream from the crossing) is too few seconds away from the crossing to be able to bring the vehicle to a safe and comfortable stop. This "entrapment" is a common occurrence.

Drivers, aware they are approaching a crossing and that the signals are not flashing, and wishing to avoid the likelihood of entrapment by the signal, have basically two options. They can either **slow down** and thus reduce the amount of time necessary to stop should the signal begin to flash, or -- alternatively -- they can decide to **increase approach speed** and thereby reduce their exposure time to the possible occurrence of an unobeyable signal. Although both decisions would appear to be quite sensible to the individuals concerned, the fact that not all drivers choose the same option leads to increased speed variance between drivers, and thus to increased accident likelihood between highway vehicles. (Recall that about two-thirds of all collisions at crossings involve no train, and that most of these occur between vehicles travelling in the same direction; Schoppert and Hoyt, 1968, Table 3).

The choice of speed is further influenced by the **roughness of the crossing surface** which poses different implications for drivers of different types of vehicles. In fact, approach speed has been found to depend more on variations in crossing roughness than on differences between the kind of signalization protection in place (Sanders, 1975). Speed variance is further enhanced by the fact that vehicles in some categories are required by law to stop at all railway crossings, while others are not (Wilde *et al.*, 1975, 1976; Hauer, 1984).

Deliberate disregard for the signals is stimulated by **long warning periods** and **false alarms**. Even when a signal is actually being perceived and obeyable (given driver distance and speed at the moment of its onset), it may not be perceived as **credible**. An activated signal does not invariably imply immediate train approach. Conversely, an unactivated signal is not always interpreted by drivers as meaning that no train is approaching (or else a considerable proportion of them would not engage in active visual search for possible train approach and come to a complete or near-complete stop before entering the crossing, although at that point in time the signals are not flashing; Wilde *et al.*, 1975, 1976; Åberg, 1984, 1988; Draskóczy, 1988).

Concern for time delays due to long warning periods and false alarms, as well as long total signal durations, induce some drivers to speed towards the crossing when the lights are not activated, to do likewise in the first few seconds after signal activation, and to pass through the crossing after first having come to a stop (or even to make a U-turn).

The less-than-perfect credibility of the signals is responsible for a situation of marked uncertainty on the part of the driver as to what the appropriate response should be when approaching a railway crossing, and hence to within-driver as well as to between-driver variance in action. (Note that this holds when the driver is wittingly approaching a crossing and the signal is or is not activated).

As in other situations where the actual significance of the activated or unactivated signal -- even if the latter is correctly perceived -- remains unclear to the individual and when motivational forces press the individual to act in one way or another, the opportunity is created (as may be extrapolated from Welford, 1968, pp. 29-37) for the occurrence of two types of risky decisions:

(a) to stop at a crossing when in fact no train is immediately forthcoming; and
(b) to pass through a crossing although in fact train approach may be imminent.

The first decision is risky, because it is made by some but not by all individual drivers. Variance in approach speeds is enhanced and thus the likelihood of rear-end or side-swipe collisions between highway vehicles. The second decision is risky because it entails the same source of risk as the first, as well as the risk of colliding with a train.

The second decision increases in subjective utility and thus becomes more appealing to drivers when:

(1) the frequency of false signals (i.e., train approach is in fact not imminent) relative to the frequency of valid signals is high;

(2) the duration of warning time is perceived by drivers as longer than necessary (the driver will thus be inclined to treat the initial part of it as if it were an "amber" period);

(3) trains occupy a crossing for long periods of time (drivers will thus be tempted to "beat the train" to the crossing);

(4) trains are rare and/or approach a crossing at a point in time in which they are not expected by drivers (relevant at crossings protected by crossbucks only);

(5) the perceived value of the decision to pass is high (a signal -- if it is there -- may be activated, but the driver sees an opportunity to cross with impunity and thus to gain time);

(6) the perceived cost of the decision to stop is high (e.g., the driver does not wish to lose time, or sense the wrath of drivers behind who wished the driver up front would proceed, or wishes to avoid being hit by a fast car behind);

(7) the perceived benefit of the decision to stop is low (the driver may view this decision as serving no useful purpose); and

(8) the expected cost of the decision to pass is low (e.g., the driver is aware that a train is approaching but expects it to stop when the locomotive engineer sees what is happening, or that any accident would be only minor).

The above factors exemplify the determinants of the amount of risk a driver is willing to accept in return for the expected benefit of mobility and of specific manoeuvres in various traffic situations, with special reference to those occurring at railway crossings. They have been elaborated further elsewhere (Wilde, 1982, 1988).

Thus, for the practical purpose of safety promotion at signalized railway crossings, false alarms should be eliminated as much as possible, i.e., signals should not be allowed to "cry wolf." The driver's perceived value of the decision to disobey the signal will be smaller to the extent that warning times are kept reasonably short as well as the total durations of trains occupying the crossing (i.e., when trains are short and travel fast).

In summary, it would seem to follow from this study that safety at crossings with all forms of protection -- short of grade separation -- could be improved by increasing crossing conspicuity, by reducing the occurrence of unobeyable signals, by smoothening crossing surfaces, by reducing false alarms and excessively long warning periods, and by shortening the total duration of signal activation. Several topics for further study are mentioned in the next section and complete this report.

5. SUGGESTIONS FOR FUTURE RESEARCH

A detailed description of suggestions for research, development and implementation for the advancement of these objectives is beyond the scope of the present report. The interested reader is referred to earlier reports on this topic (Wilde *et al.*, 1975, 1976) and to Hauer (1984) and Hauer and Wilde (1987) for a more recent and more exhaustive discussion. The Hauer and Wilde report covers a wide variety of research issues. Here we have selected a number of topics from that report which specifically deal with improvement of driver behaviour at railway crossing through environmental and equipment design.

5.1 The Potential Benefits of a Bi-directional Signal Indicating that a Train is Approaching Either from the Left, the Right, or Both

Any motorist approaching an intersection with a one-way or two-way street is informed by signs of the direction or directions of traffic with which he or she could potentially collide. This is presently not the case for drivers approaching a railroad crossing. Several train-vehicle accidents, although it is not known to us how many or what percentage, have occurred because drivers assumed that they could safely proceed after a train coming from one direction had passed, only to inadvertently hit or be hit by another train entering the crossing from the other direction.

This could happen in association with the occurrence of false alarms as observed in the present study. Drivers, realizing that the stopped eastbound train in the Kingston station triggered the invalid warning signals, may be tempted to drive around the barriers (as in fact they did as documented on videotape; see Table 2), while not realizing that a train could be approaching from the other side.

We, therefore, suggest that research be undertaken into the feasibility and potential safety benefits of providing active crossing signals with an indication of the direction or directions from which a train or trains are approaching.

5.2 The Potential Benefits of a "Fail-safe" Signal

In the present study it was noticed that during the strike (a period in which the signals were credible, i.e., people had reason to assume that no train would be coming), drivers altered their approach behaviour, indicating that their uncertainty had been reduced. In some countries efforts have been undertaken to counteract the major problem of lack of credibility of active warning signals at crossings. For instance, crossings with flashing lights in Sweden are equipped with a white intermittent light which is activated whenever the red flashing lights announcing train approach are not in operation (Åberg, 1984, 1988). Consequently, when approaching drivers see no activated light at all at such a crossing, they are in fact told that the signalling system is out of order. As we know of no study looking into the effects of such a failsafe signal upon driver behaviour or crossing safety, but as we seem to be dealing here with a comparatively simple method for adding some credibility to warning signals (although, of course, only when they are off), this question may well merit further investigation, as is also mentioned by Shinar and Raz (1982, p.807).

5.3 The Resting Position of the Nonactivated Barrier as an Aid to Crossing Conspicuity

Another simple suggestion may be made for the enhancement of crossing conspicuity and has to do with the position of the barrier when this is not lowered. At present it is in a vertical position, that is to say, in a position that is not clearly distinct from the vertical. The general road environment is characterized by the presence of many vertical objects and contours, like buildings, trees, walls, fences, and telephone and power poles. Therefore, conspicuity of the barrier and thus of the presence of a railroad crossing could potentially be enhanced if the unactivated barrier were to lean slightly but noticeably toward the roadway. [Alerting devices such as rumble strips on the road pavement are in our opinion not advisable, in the first place because it is not clear what they signal (drivers may think there is something wrong with their car), and secondly because they may startle drivers and thus do more harm to safety than good].

5.4 The Safety Implications of Crossing Surface Roughness

One of the variables in which crossings differ is the degree of smoothness or roughness they present to passing drivers. As noticed in Section 4, different divers may have different expectations of this crossing characteristic and they react differentially to it in terms of approach speed. Speed choice will thus in part depend upon a driver's degree of familiarity with the crossing, but also upon his or her tolerance (in part determined by the shock-absorbing capacity of the vehicles they operate) for an unpleasant ride across it. Thus, the fact that not all crossings offer the same degree of vibration discomfort may be expected to enhance between-vehicle speed variance and, consequently, the likelihood of accidents involving motor vehicles at these sites.

However, it would be reasonable to suppose that crossing-surface roughness may also increase the likelihood of collisions between vehicles and trains. This is because a rough crossing generally leads to a speed reduction; in fact, approach speeds have been found to vary more as a function of crossing roughness than of the type of protection present (Sanders, 1976, Figure 3, p.31)! The motor vehicle will thus spend more time on the crossing and the likelihood of it being hit by a train is enhanced.

Moreover, it has been observed that in as many as 18% of all train-vehicle collisions in which the train hit a motor vehicle, the latter was not moving at all, but standing on the crossing (Schoppert and Hoyt, Table 8, p.9). We do not wish to imply that all of these 18% were due to crossing roughness, although combined with low approach speed it undoubtedly increases the chances of engine stalling.

Should all crossings be equally rough or equally smooth? It would seem that they should be equally smooth, because a rough crossing surface constitutes a greater obstacle for some vehicles than for others, while a smooth surface has the same consequences for all vehicles. Thus, equally smooth crossings may be expected to elicit more homogeneous approach behaviour and less driver distraction (Draskóczy, 1988) than crossings that are equally rough.

In short, there may well be reason to investigate to what extent the occurrence of roadway vehicle and of train-vehicle accidents depends upon the degree of vertical acceleration induced by the meeting of rail track with road pavement.

5.5 The Sequential and Standardized Warning Signal System (SSWS)

5.5.1 Background. Some time ago, further research and development was recommended towards the form of railway crossing protection with flashing lights (with or without barriers) that has been proposed under the above name (Wilde, Cake and McCarthy, 1975). This signalling system would seem to be capable of:

(a) reducing the likelihood of a driver meeting with an unobeyable signal;

(b) reducing the lack of credibility of signals announcing train approach; and

(a) improving driver awareness that he or she is approaching a signalized railroad crossing.

Before describing this signalling system -- which essentially combines grade crossing predictors with active advanced warning -- in some detail, we will first elaborate here on the significance of the "unobeyable signal problem." That signals lack credibility and that the presence of a crossing and the approach of a train often lack conspicuity have already been belaboured in the available literature (Hauer, 1984; Shinar and Raz, 1982; Leibowitz, 1983) as well as in the present report.

The flashing alarm signals as used in Canada and the USA, although they appear to convey the unambiguous commands of either "stop" or "proceed," actually cannot be obeyed under certain conditions. If a driver is at a considerable distance from the crossing when the lights begin to flash, it will of course be obvious to him or her that a stop is called for. Thus, this driver should have ample opportunity to brake at a comfortable rate of deceleration and to come to a safe stop before the crossing.

However, if a driver is very close to the crossing at the moment at which the lights start to flash, he or she may not be able to make a safe and comfortable halt before reaching the crossing, and thus be compelled to disobey the signal and to enter the crossing after signal onset.

The likelihood of such an occurrence is not all that small, as can be seen from the following. Let "v" be the vehicle speed in m/sec and "a" the tolerable deceleration rate in m/sec2. Thus, the minimum time needed for a comfortable stop is "v/a" seconds. Driver reaction time in deciding what action to take is "t" seconds and "w" represents warning time in seconds, warning time being the interval between signal onset and actual train arrival at the crossing.

The probability of an approaching car being unable to come to a safe and comfortable stop, given that this car is within "w+t" seconds of uninterrupted travel from the crossing at signal onset, and assuming that "(w+t)>(v/a +t)", equals a fraction:

$$(v/a + t)/(w + t) \text{ per car} \qquad (1)$$

For each signal activation period per hour (i.e., 3600 seconds), the probability of a car being on the approach road within "w+t" seconds away from the crossing before the train reaches it equals:

$$(w + t)/ 3600 \text{ per approaching car} \quad (2)$$

Thus, if there are "C" cars and "T" trains per hour, the number of cars, "N", which are unable to stop, equals the product of "C", "T", expression (1) and expression (2):

$$N = \frac{C \times T \times (v/a + t)(w + t)}{3600 \times (w + t)} \quad (3)$$

which simplifies into:

$$N = \frac{C \times T \times (v/a + t)}{3600} \text{ per hour} \quad (4)$$

In practice, "w" may be estimated to average approximately 51 seconds in the US (calculated from Sanders, 1976) and to vary between an average per crossing of 29.6 and 11.65 seconds at six crossings in eastern Ontario, with standard deviations ranging from 13.1 to 53.1 seconds (Wilde, Cake and McCarthy, 1976, Appendix E). A minimum tolerable deceleration rate "a" is approximately 3 m/sec2 (May, 1965). Driver reaction time, "t", under conditions of decision uncertainty may be estimated to amount to about 2.5 seconds (Shinar and Raz, 1982).

So, if we consider a crossing with a vehicle approach volume (from both sides combined), "C", of 600 cars per hour and a train volume, "T", of three per hour, and if we assume that all cars approach the crossing at 80 km/h (i.e., 22.22 m/sec) at equal distances between them, an expected number, "N", of:

$$N = \frac{600 \times 3 \ (22.22/3 + 2.5)}{3600} = 4.955$$

or about five cars per hour will be faced with the inability to stop. This is equivalent to 4.955/600 = 0.83% per approaching car.

Thus it may be inferred that the current signalization system forces a significant number of drivers to violate the signals and that inability to stop is not an extremely rare event. This percentage is high if one compares it with the risk of a driver being charged when speeding which has been estimated in Canada to be in the order of 1/7200 (i.e., 0.014%), or being convicted for driving over the legal blood-alcohol limit which amounts to one conviction per approximately 26,000 kilometres of driving while over that limit (Road and Motor Vehicle Traffic Safety, 1974).

As the term "w" cancels out in Equations 3 and 4, the frequency of this occurrence cannot be influenced by either shortening or lengthening the warning time period. If it were shortened, fewer cars would be "trapped," but a larger proportion of those trapped would be unable to stop; if the warning period were made longer, a smaller proportion of drivers would be unable to stop, but a commensurately larger number of them would be trapped.
Driver approach speed, on the other hand, does have an effect. The lower this speed, the smaller the likelihood of meeting with an unobeyable signal: the term "v/a" drops, but the likelihood of the problem is not commensurately reduced by the extent to which "v", i.e.,

speed, is lowered. In fact, its likelihood diminishes more slowly than speed reduction, and this is due to driver reaction time "t" which dampens the beneficial effect of speed reduction (see Equation 4).

However, it should be noted as well that drivers who do not lower, but instead maintain or increase their speed, also reduce the likelihood of meeting with the potential occurrence of an unobeyable signal. This is because they diminish the likelihood of the signals beginning to flash in the time lapse between approaching and clearing the crossing. At these sites, both turtle and hare make very good sense in their efforts to reduce the potential of a train-vehicle collision, but they do this at the unfortunate expense of increasing the likelihood of collisions between the two species even without a train approaching, let alone being involved.

5.5.2 Summary description of the SSWS design. How then can one develop a warning system that provides the driver with unambiguous stop and go instructions (and thus reduces decisional uncertainty) without demanding that he or she do the impossible, that is coming to an immediate stop when he or she is very close to the crossing when the signals start to flash?

Obviously by having the signal indicate to the drivers not what they should do before arriving at the location of the signal, but what they should do next, that is after passing the signal location.

A system that appears to satisfy this requirement as well as to enhance signal credibility has been diagrammed in Figure 8.

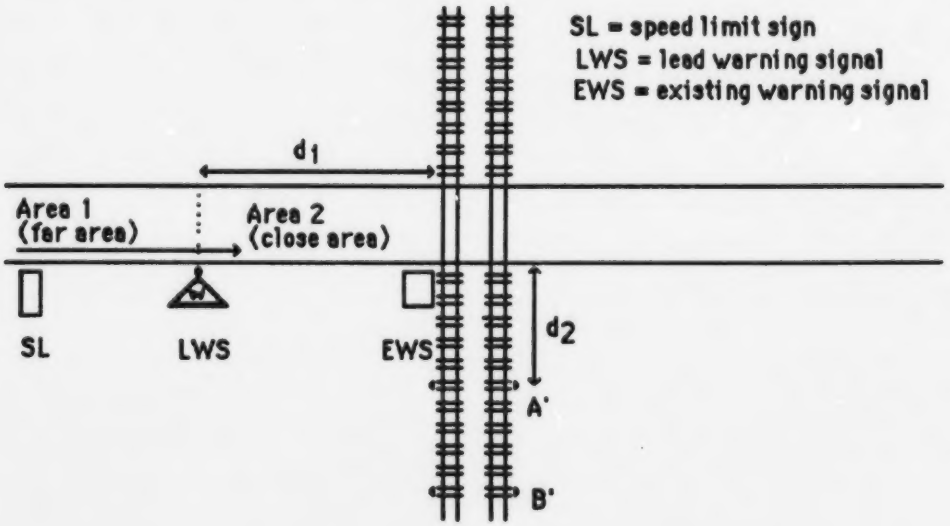

Figure 8: Schematic diagram of the sequential and standardized warning signal system (adapted from Wilde *et al.*, 1975).

The system will be called the Sequential and Standardized Warning Signal (or SSWS) system. It is sequential in that it provides for two spatially separated warning signals, the first one of which is activated some time before the second. It is standardized because the activation of both warning signals precedes the arrival of the train by constant time intervals for all crossings where it is installed and for all trains. What follows is to a large extent a repetition of what has been said about the SSWS system in earlier reports (Wilde, Cake and McCarthy, 1975, 1976).

We feel that this repetition is justified because the signalling system in question, although it may seem "utopian" at first sight, may help clarify the rationale for potential procedures and technologies and assist in the identification of what a railroad crossing -- short of grade separation -- might look like in the ideal case.

As compared to the warning system presently in existence, one major modification is the addition of a lead warning signal (LWS) on each approach side of the crossing. This is located some distance (to be defined below) ahead of the existing warning signal (EWS) at the crossing. While no major change in the physical layout of the EWS is needed, the lead warning signal should be given a distinct appearance. For instance, it could take the form of a triangular display containing a train silhouette that can be illuminated intermittently, equipped with bells and a fail-safe signal mounted on top.

The LWS is a simple stop/go instruction device. If it is activated, it indicates to a driver in Area 1 (the far area) that he or she is supposed to stop the vehicle before the crossing, that is in Area 2 (the close area). If the LWS signal is not activated when the driver enters Area 2, he or she is expected to proceed through the crossing at the prevailing speed limit. Note that a speed limit sign is placed at a relatively short distance upstream from the LWS (see Figure 8). If the failsafe signal is not operating, this indicates that the warning signal is malfunctioning. In that case, the driver is expected to proceed with caution and look both ways before negotiating the crossing.

In order to make the instructions conveyed by the LWS signal meaningful and realistic, several conditions must be fulfilled. First, the LWS should be located at a distance "d1" from the EWS, such that the driver can safely stop in the area between the LWS and the EWS (Area 2), assuming that he or she is travelling at the posted speed limit. (In practice, it may be preferable to conduct observational studies to determine whether the speed limit is being observed or often exceeded and appropriate adjustments in the spatial separation between the LWS and the EWS may be made accordingly.)

Secondly, the activation of the LWS should precede the activation of the EWS and the actual arrival of the train by fixed time intervals. This may be achieved by activating the lead signal a constant amount of time prior to (predicted) train arrival at the crossing. The EWS also begins to flash by a fixed amount of time prior to train arrival at the crossing, but this time interval is somewhat shorter than the interval between the LWS onset and train arrival. The LWS and EWS are de-activated at the same time (when the train has cleared the crossing). As a result, all three time intervals are constant.

The time interval between LWS onset and EWS onset has already been mentioned. The distance "d1" is calculated accordingly. LWS onset is controlled by means of a level crossing predictor. In Figure 8 this is represented by two train presence sensors placed at point B' and A' along the track. Thus, triggering of the LWS (and subsequently of the

EWS) is determined by the time taken by the first unit of the train consist to travel between these points and the distance "d2" between A' and the actual crossing. For this system to work, it is necessary that the train maintain a constant speed between B' and the crossing. At locations where train acceleration or deceleration cannot be avoided, a more complicated procedure for crossing prediction may be called for.

We also wish to stress that this description is merely intended to illustrate a design principle; more sophisticated approaches to grade crossing prediction technology may well be available already, or could be developed if the principle proposed here were judged to be promising.

The distance "d2" must be great enough to allow a road vehicle travelling anywhere in Area 2 (the close area) to clear the crossing proper prior to EWS onset. Vehicles moving at the posted speed limit or faster would pose no problem, but slower vehicles might. Therefore, it is necessary to maintain a safety margin, that is, a fixed time interval between EWS onset and the predicted moment of train arrival.

The safety margin should be chosen with great care. If it is too long, both EWS and LWS would lose credibility, and if it is too short, a hazard would be created for very slow moving vehicles that are in the close area (Area 2) after LWS onset but prior to EWS onset. Fortunately, however, safe stopping distances for these vehicles would be rather short because of their low moving speeds. Thus, the time lapse between EWS onset and train arrival might be chosen in the order of, say, 12 seconds, but additional study will be necessary to arrive at a truly judicious choice.

Further conceptual analysis reveals that the SSWS design may indeed be expected to greatly reduce the problem of the unobeyable signal, but it cannot totally eliminate this problem.

In order to produce constancy of all time intervals within as well as between crossings, the distances "d1" and "d2" are calculated on data that are pertinent to each crossing separately. Distance "d1" is chosen such that it provides sufficient braking distance for the fastest moving vehicle and for the vehicles with the poorest braking capability, while taking account of the lowest pavement friction under adverse weather conditions. Next, we determine how many seconds it takes to complete this braking manoeuvre in a safe and comfortable manner. We add a small constant, say 2.5 seconds, to allow for driver reaction time. The sum total of reaction time plus maximum braking time in the worst possible case would, of course, have to be calculated from empirical data, but for the sake of the present discussion let us assume that it does not exceed 20 seconds. Thus, LWS onset would precede EWS onset by 20 seconds at all crossings equipped with SSWS, and actual train arrival by 32 seconds.

5.5.3 Implications of the SSWS system. It is our opinion that the SSWS system would do much to elicit road user behaviour that is more compatible with the demands of safety. This may be explained by the following considerations.

A driver, who is in Area 1 (the far area) when the LWS and EWS signals are off, is instructed to continue on his way at the posted speed limit without decelerating or stopping. This driver will also expect other drivers ahead of him or her to do the same. Consistency would demand abolition of the present requirement that certain classes of vehicles always come to a full stop at crossings. When the LWS signal is on and the EWS is off, the

driver who is approaching in Area 1 is instructed to stop in Area 2 (the close area) and he or she will expect any vehicles ahead or behind (in Area 1) to do the same.

The number of drivers who pass an inactive LWS signal, but encounter an activated EWS signal while driving in the close area should be very small, because this situation can occur only if their moving speed is very low. As a consequence, these drivers should have little difficulty in stopping. Thus, it may be inferred that the SSWS system does not only enhance the predictability of the behaviour of signals and trains to a maximum, it also makes it much easier for any driver to accurately predict the behaviour of other road users ahead of him or her.

In relation to vehicle approach variability within and between crossings, various studies have observed considerable heterogeneity in speeds, patterns of acceleration and deceleration and also in head movements. In the view of the authors, the first two factors are related to the latter. Part of the speed and acceleration/deceleration variability may be a result of drivers' decisions to look or not to look along the track. Some drivers may decide to cope with the present crossing situation by attempting to reduce danger time to a minimum. Perhaps these drivers decide to devote full attention to proceeding through the crossing as quickly as possible and hence do not look left or right. In support of this interpretation it may be recalled that a negative relationship has been found between the head movements and the speed at which the crossing is negotiated (Wilde, Cake and McCarthy, Table 6, p.38 and Appendix C in the same reference). Other drivers, who perhaps have less confidence in the present warning system, decide to look, slow down, and thus incur an increased crossing occupancy time as well as an increased likelihood of being hit from behind.

A fully credible SSWS system would eliminate altogether the need to look at things other than the road and the signals themselves, except in the rare cases in which the fail-safe signal is in operation. As a result, the need to slow down would be reduced. At first sight, it may seem odd, if not foolish, to discourage drivers from looking left and right. However, to reduce behaviour variance, either all drivers should look or none. The first condition may be created either through complete removal of all active warnings, or by making them totally unreliable. As this is obviously not advisable, we should try to circumvent the need to look altogether. However, this poses a heavy burden upon the reliability of signal functioning.

Thus it would seem that the SSWS system, by removing one major source of turbulence in traffic flow, may be expected to bring about driver behaviour that is more compatible with the needs of safety.

5.5.4 SSWS and crossing conspicuity. Up to this point our discussion and suggestions in Section 5.5 have focussed upon the decision-making aspect of the driving task. That is, we have reasoned as if we assumed that drivers are aware they are approaching a railroad crossing and do perceive the signals. Such assumption, of course, is false. However, it is not known in what proportion of collisions between trains and vehicles drivers are not aware of the train approaching. A Japanese study (Ikeda, 1971) arrived at an estimate of about one-third, but this may well be an overestimate if we consider that it was obtained from interviews with motorists who had survived their collision with a train and some of them may have mentioned lack of awareness as an excuse for having caused an accident. Schoppert and Hoyt (1968) calculated that in about two-thirds of 15,554 train-vehicle collisions, the vehicle was hit by the train, while the train was hit by the vehicle in the

remaining one-third. These authors reckoned that about 13% of all collisions with trains occurred when the train had already reached the crossing while the motorist was still far enough away from the crossing to allow a complete stop. Schoppert and Hoyt seem to accept this 13% as an estimate of the proportion of accidents due to lack of awareness, but they seem to have overlooked the fact that this estimate should also be applied to the remaining 87%. If this is done, we arrive at an estimate 13% + 0.13 x 87% = 24%.

So, as many as one-fourth to one-third of all train-vehicle crashes may be estimated to be due to driver unawareness. Some benefit of the suggested SSWS system in alleviating this problem may be derived from the conspicuous lead warning signal in addition to the existing warning signal. (For another potential aid to crossing conspicuity, see Sections 5.2 and 5.3).

5.6 The Relationship between Lateral Sight Distance and Crossing Safety

Finally, we suggest that further research be conducted in order to clarify the somewhat puzzling findings in existence regarding the question of whether or not lateral sight distance has an effect upon the accident frequency at railway crossings. By "lateral sight distance" is meant by how many metres a driver can look down the railroad track to the left and to the right when he or she is at a given spatial distance (e.g., 100 m) or temporal distance (e.g., 10 seconds, assuming that speed remains constant) when heading for a crossing.

This variable is represented in some of the formulas that have been developed in order to predict the future numbers of accidents between trains and highway vehicles at railway crossings of different characteristics. The detailed discussion by Hauer and Wilde (1987) of these formulas shows that this variable is absent in others, including the DOT and Coleman-Stewart models, although the latter two have been found to rank highest in predictive validity in the USA.

In their retrospective calculation of hazard indices for highway-railway crossings in Canada, Zalinger *et al.* (1977) observed that the (spatial) sightline at 300 feet "makes a measurable contribution to the prediction of crossing accidents only in rural areas. The coefficient of this variable is fairly small and an increase from 100 to 500 feet in this sightline will reduce the hazard only by 0.009" (*op. cit.*, p. 265).

While noting that this crossing characteristic "has never been shown as a strong variable," Schoppert and Hoyt (1968, p. 27-29) remark that "this does not seem logical; sight distance should be one of the most important variables. If the driver cannot see [....] down the track an adequate distance, then he and his vehicle are being expected to perform beyond their physical limitations." These authors suggested that the anomaly is due to inadequacies in the manner in which sight distance data were collected. They subsequently made a serious attempt to develop better data collection procedures and applied these to the ten-year retrospective records of accidents at 31 crossings with crossbucks only. Yet, they reported that "no correlation was found between accidents and either of the sight distance criteria" (*op. cit.*, p. 29), and attributed this lack of correlation to insufficient variance in the variables considered.

However, for the above pattern of findings there may be an alternative explanation of a rather different nature. Consider the possibility that drivers, when seeing that lateral visibility along the railway track is limited, decide to reduce speed to be able to observe a

distance down the track at a point on the road that is closer to the crossing. In doing so, they could in fact achieve the same temporal sight distance regardless of the spatial sight distance of the crossing in question. If drivers make such behavioural adjustments to variations in visual obstruction of the track, then there is no reason to expect a significant association between visibility characteristics of crossings on the one hand and their accident frequency on the other.

This hypothesis of adjustment in speed and visual search could be tested by observing driver approach behaviour at a sample of crossings chosen for their diversity in visibility features. The evidence could be strengthened by adding an experimental component to the naturalistic observations. The experimental component could consist of improving the sight distances at some crossings and of observing the ensuing changes in driver behaviour in before/after comparisons.

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